LIFECYCLE ASSESSMENT FOR STRATEGIC PRODUCT DESIGN AND MANAGEMENT

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LIFE CYCLE ASSESSMENT FOR STRATEGIC PRODUCT DESIGN AND MANAGEMENT

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NOMENCLATURE

Abbreviations

CRT:	Cathode Ray Tube
D:	Digital imaging system
EU:	Energy Use
GE:	Greenhouse Emmissions
H:	Hybrid traditional and digital imaging system
ISO:	International Standards Organization
LCA:	Life Cycle Assessment
LCD:	Liquid Crystal Display
P:	Product system
PC:	Personal Computer
PSS:	Product service system
SETAC:	The Society of Environmental Toxicology and Chemistry
T:	Traditional film imaging system
WG:	Waste Generation
WU:	Water Use

Units

kg:	kilograms
kg CO2 Eq.:	Kilograms CO_2 Equivalent measure of greenhouse gas emission
kWhr:	kilowatt hour
m^3:	cubic meters
MJ:	MegaJoules

Imaging Processes

FC: Film Capture

DC: Digital Capture

RFP: Retail Film Processing

WFP: Wholesale Film Processing

CRTP: Digital Personal Computer / Cathode Ray Tube Monitor Image Processing

LCDP: Digital Personal Computer / Liquid Crystal Display Image Processing

RP: Retail Printing

WP: Wholesale Printing

CRTIO: Digital Personal Computer / Cathode Ray Tube Monitor Inkjet Printer Output

LCDIO: Digital Personal Computer / Liquid Crystal Display Inkjet Printer Output

CRTD: Digital Personal Computer / Cathode Ray Tube Monitor Display Image Output

LCDD: Digital Personal Computer / Liquid Crystal Display Image Output

Imaging Scenarios

FC/R: Film Capture, Retail Processing and Retail Print Output

FC/W: Film Capture, Wholesale Processing and Wholesale Print Output

DC/CR: Digital Capture, Digital Processing via PC with a CRT monitor and Retail Print Output

DC/LR: Digital Capture, Digital Processing via PC with an LCD monitor and Retail Print Output

DC/CW: Digital Capture, Digital Processing via PC with a CRT monitor and Wholesale Print Output

DC/LW: Digital Capture, Digital Processing via PC with a CRT monitor and Wholesale Print Output

DC/CI: Digital Capture, Digital Processing via PC with a CRT monitor and Inkjet Print Output

DC/LI: Digital Capture, Digital Processing via PC with an LCD monitor and Inkjet Print Output

DC/CD: Digital Capture, Digital Processing via PC with a CRT monitor and PC with CRT Display Output

DC/LD: Digital Capture, Digital Processing via PC with an LCD monitor and PC with LCD Display Output

ABSTRACT

With the advent of digital imaging technology, the options available to consumers in consumer imaging have increased tremendously. From image capture through image processing and output, many options have emerged; however, the relative environmental impacts of these different options are not clear cut. Simplistically, one might say that the use of a digital camera has a lesser environmental burden than the use of a reloadable film camera because the image produced as a result of using the digital camera avoids chemicals in film developing. However, digital cameras require electronics and computers that need energy; and, energy production is one of the contributors to greenhouse gasses like CO_2. Assessment of the environmental impacts of these different options can help provide feedback to decision makers and insights that will help reduce environmental impact through product system design.

One tool that has been used to relate environmental impacts with functions provide to consumers through products or services is Life Cycle Assessment (LCA). LCA, which has been standardized by the International Standards Organization (ISO) in ISO14000, is used here to evaluate both traditional film and digital imaging systems. Data from publicly available databases and both external and internal Eastman Kodak Company studies were utilized to develop LCA modules for the different processes involved. Product and service business models are explored for both technologies through ten different imaging and output scenarios. The functional unit used is the capture, processing and output of one 4”x6” image. Four impact categories (energy use, greenhouse emission, water use and waste generation) across four life cycle phases (upstream, distribution, use, and end of life) are explored for the ten scenarios.

LCA is also evaluated as a tool to help facilitate strategic level environmental performance issues with both new and established business activities. Sensitivity analysis is also performed to evaluate the impact of assumptions made in the course of the assessment and comments are made regarding the effectiveness of LCA for strategic assessment and product service strategies in lowering environmental impact.

Results indicate that the lowest impact scenarios are Digital Capture to LCD Display for Greenhouse Emissions and Energy Use and Film Capture to Wholesale Print for Water Use and Waste Generation. Highest impacts were seen for Greenhouse Emissions in the Film Capture to Retail Print scenario. In the Energy Use and Water Use category, the Digital Capture to CRT Computer Display was the highest scenario. For Waste Generation, the Digital Capture to Inkjet Print was the highest impact scenario.

CHAPTER 1 – INTRODUCTION

1.1 Environmental Impact of Industrial Activities

From our beginnings, human beings have had interesting and complicated interactions with other organisms and our environment. From our early, hunter-gatherer societies to our modern technological society we, as a species, have made far-reaching changes to both ourselves and our environment. Domesticating animals, developing agriculture, even fermentation have dramatically altered either our environment or our societies. Perhaps some of the most powerful and concentrated affects of our interactions with our environment have been seen in industrialization.

With the Industrial Revolution, manufacturing had both positive affects on society, such as employment and widespread availability of inexpensive products and negative affects such as, concentrated pollution and some social changes. As these new challenges were faced, changing technologies add to the challenge of wrangling industrial environmental impact. Additionally, as world population and industrialization increases and more resources are tapped, the benefits of industrialization will spread; and, so to will the negative environmental impacts. As these impacts concern everyone, a concerted effort amongst all groups, corporations, consumers and governments, is required to help mitigate these impacts.

Science can be used to address these issues from a variety of angles. One group, The Society of Environmental Toxicology and Chemistry (SETAC) approaches things, as their name implies, on the chemistry of industrial interactions with the environment. SETAC focuses on a science based, multidisciplinary approach to environmental issues with a mix of industry, academic and government involvement. Their work helped to develop an analysis tool called Life Cycle Assessment (LCA) which was later standardized by the International Standards Organization (ISO).

Dr. Karl-Henrik Robèrt, a Swedish scientist, developed a set of system conditions for sustainability based on engineering principles.[1] These principles provide a perspective of environmental issues at a higher level of abstraction. This higher level of abstraction can be helpful for analysis of systems which are very large and complex; especially when data from the entire life cycle of a particular system may not be completely available. For example, when approaching things from a toxicological point of view, there are a many factors that are involved in assessing its toxic potential. From the type and amount of a substance, to the percent in solution, the end fate and any processes involved in mitigating its affects, all of these can alter the effects on the environment.

One potential means to reduce environmental impact from industry is the development of new technologies. Different technologies that fulfill the same, or nearly the same, functions may have drastically different material or energy requirements to achieve these similar functions. This substitution of one technology for another may have more potential to change the environmental impacts than focusing on incremental improvements of existing designs. However, newer technologies are far from guaranteed to have lower environmental impacts. A drastic change in the means to achieve a specific function may shift from one type of impact to another; or, from one part of the life cycle to another. Any environmental comparison of different technologies thus must include several different types of impact assessment as well as a broad perspective over the system's life cycles.

1.2 Consumer Imaging

One example of a consumer function that has undergone transitions of technologies and types of processes is that of consumer imaging. Consumer imaging can be viewed as a system of interactive products and services that work together to provide a collection of functions including image capture, image processing and image output. With the advent of the digital camera, consumers have more options than ever in selection of the processes that they use to provide these imaging functions. These options cover the range of different technologies as well as different ways of applying technology as a product or a service system. From digital to traditional image capture and digital home inkjet image output to traditional retail or wholesale image output, the range of consumer options that exist currently is very broad.

Figure 1: Examples of consumer imaging systems

There are several types of differences in these imaging system options. Different technologies, business models and types of print instantiation all contribute to the range of products and services available today. Technologies differences appear between traditional film imaging systems and digital systems. Traditional film capture processes are fairly well established and cover the consumer imaging functions from film capture through retail and wholesale image processing and printing. Digital systems are a relatively recent addition to the consumer imaging options and comprise not only digital capture, but also processing and printing via personal computer and inkjet printer.

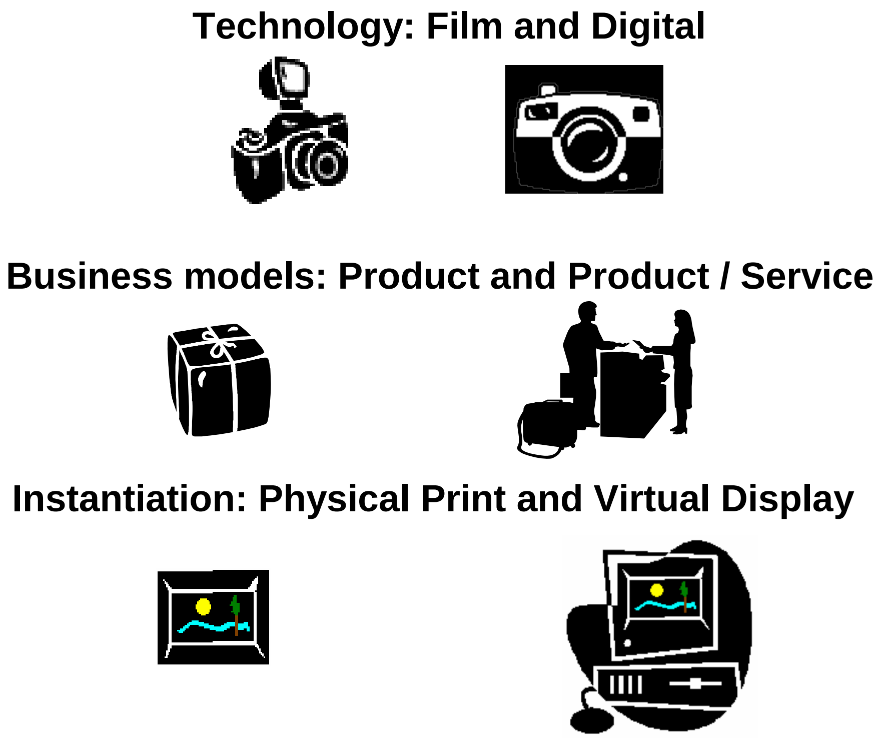

Figure 2: Imaging system differences

Traditional film imaging systems have relied on a hybrid, product service business model. The image capture processes are generally offered as products, specifically film and cameras; while the processing and output processes revolved around a service business model. With the introduction of digital imaging, consumers have the option of purchasing products that provide all of the imaging functions or choose to rely on service systems like with film imaging. Furthermore, with the option of image display via a digital display, CRT or LCD, consumers have the option of image output as physical print or a digital display.

The products and services can be seen as processes with different inputs and waste outputs but providing the same (or very similar) functional output. It is from this perspective that discrete sub-processes can be developed of the variety of different products and services involved in consumer imaging. These sub-processes can be divided into three stages, image capture, image processing and image output.

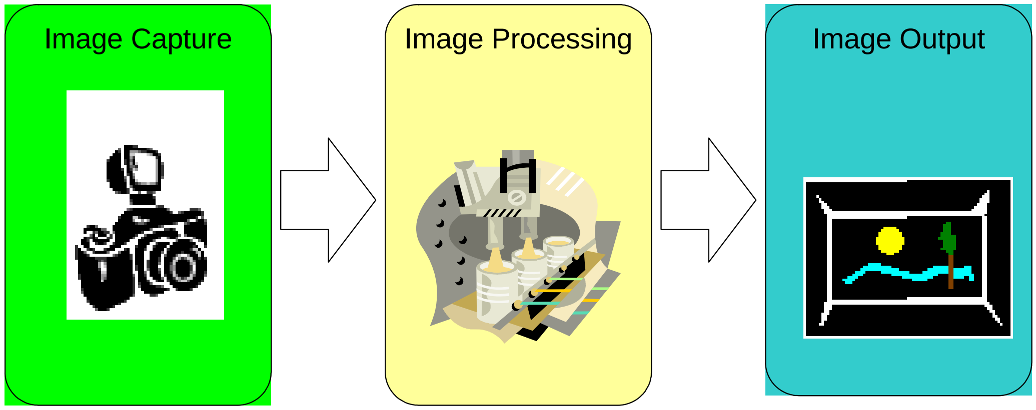

Figure 3: Stages of consumer imaging

Image capture represents the process of recording the subject onto a storage media. In traditional film technology, image capture is achieved via directing and controlling light exposure of silver halide photographic film. With digital imagery, the image is captured via either a CCD (Charge-Coupled Device) or a CMOS (Complementary Metal-Oxide Semiconductor) sensor which are comprised of a grid of phototransistors. These sensors digitize the image data and that data is then stored either on the cameras internal hard drive or a removable storage card. These two technologies are quite different, traditional film capture relying on phenomenon from chemistry and digital capture based on electronics technology. These two functionally similar processes provide an excellent opportunity to investigate technology and how different instantiations of functionally equivalent processes might have different impacts.

Image processing and printing options have developed to the point where there are various technologies in the market for these functions as well. Traditional film image processing and printing has been established in the marketplace for sometime. These processes are largely service oriented systems with the consumer dropping off film at a developer to be processed and printed. With the introduction of digital imaging technology, the range of choices consumers have to satisfy the imaging functions expanded considerably. Now new products have brought digital image processing and printing into the home further expanding the options consumers have in imaging.

The three stages of consumer imaging, defined previously as image capture, image processing and image output, can be used to help organize the different consumer options. The figure below provides an overview of these consumer options in the different imaging stages. In image capture, there are two capture technologies, film and digital capture. Image processing contains three different processes. On the traditional side it has both retail and wholesale film processing. These two processes differ primarily in scale; with retail processing centers supporting a single location and wholesale processing operations supporting several locations around a particular geographical region. On the digital side, processing is supported by a personal computer. For the final stage, image output, there are four consumer options considered. The first two, traditional processes are retail and wholesale output and are similar to those in the imaging processing stage. Computer display and computer printer output round out the different processes in image output. In this study, these processes were used to create several different pathways or scenarios to investigate.

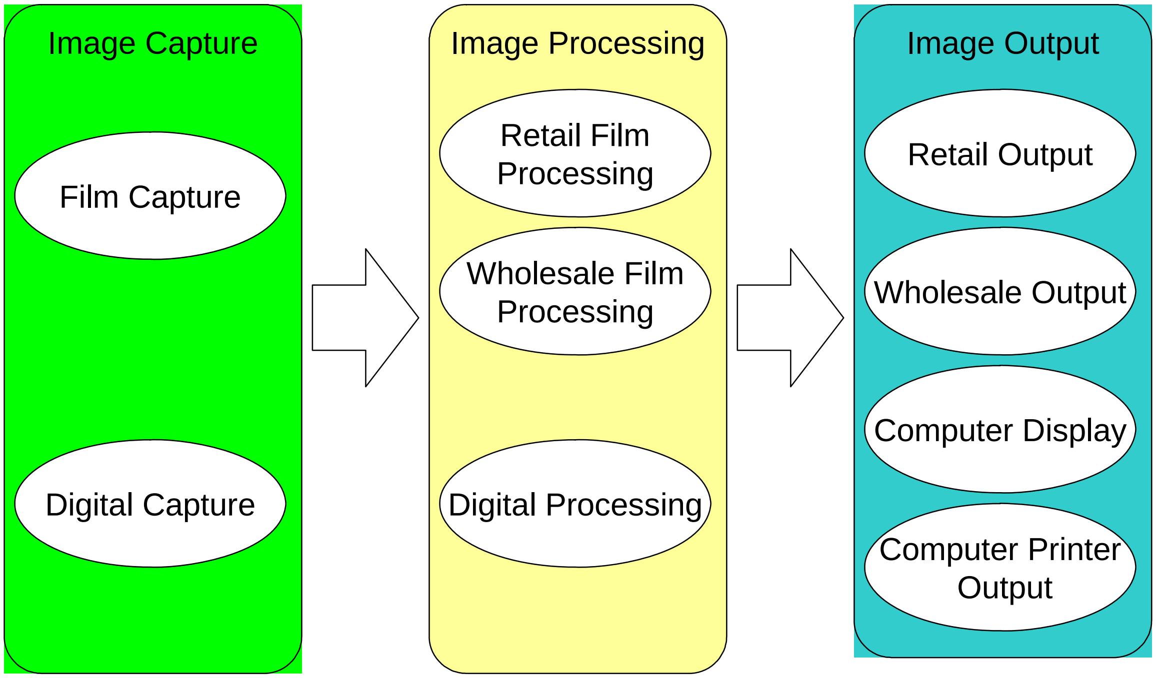

Figure 4: Consumer imaging options

The relative environmental impacts of these different options are not clear cut. Simplistically, one might say that the use of a digital camera has a lesser environmental burden than the use of a reloadable film camera because the image produced as a result of using the digital camera avoids chemicals in film developing. However, digital cameras require electronics and computers that need electricity. And electricity production is one of the contributors to greenhouse gasses like CO_2. In the summer of 2003, Eastman Kodak Company and Georgia Tech began a partnership to explore the environmental impacts of the different imaging technologies and scenarios.

Comparing digital imaging to film imaging presents some problems. With the additional functions digital cameras have in comparison to film cameras a clean “apples to apples” comparison is not possible. Digital imaging has fundamentally changed the way people capture, manage and share pictures. One of the most evident of these changes is the way people share digital images via the internet. These changes are a combination of technical feasibility and social acceptance and response to the technology.

While this subject alone is of interest and perhaps justifies its own study, it is beyond the scope of this work. This study focuses on the fundamental imaging operations, capture, processing and output. To that end, the heart of this study is the lowest common denominator of these technologies in providing the core imaging functions. That is, the idea of providing image capture, processing and output for the consumer. Each technology is capable of achieving these functions and this study is limited to how these technologies do so.

These systems provide an excellent case study to investigate using LCA for comparison of differing technologies and applications ranging from products to services. With all these options available to consumers today, it is natural to question is there an environmentally preferred method of consumer imaging, is digital better than traditional imaging? Both digital and modern film cameras heavily utilize electronics for controls and use interface, size, weight and lifetime of the cameras is also comparable. In use, both cameras use batteries while film cameras also consume photographic film to capture an image. Digital cameras capture and store images to either an internal hard drive or removable, reusable digital media. In this brief comparison of digital from traditional imaging, the differences that stand out the most is the use of photographic film in traditional imaging. In processing and output, the traditional systems have potential advantages due to economies of scale. While technology differences between the two may have some mitigating or amplifying influences on the environmental performance of these systems it seems likely that economies of scale would trump these.

1.3 Product vs. Product Service Systems

Selection of the more environmentally preferable amongst existing technologies is one example of short term solutions to environmental problems. Different methods of applying different technologies in the marketplace could also have different environmental impacts. One example of differing applications is Laundromats and washing machine in the home. Both schemes provide the same function to the consumer and use the same principle; however, the Laundromat scheme provides the function in the manner of a service while the in home machine is a product that the consumer owns. These are examples of different applications of similar (or the same) technologies and functions. Some have suggested that service systems are a valid means of reducing environmental impacts.

With the growing options in consumer photography, there are many different pathways to achieve the image capture, processing and output functions. Not only are there different technologies to choose from, but also different instantiations of these technologies in the form of different business models. Traditional photography has utilized a hybrid product / service model while digital options range from a similar product / service model to an entirely product oriented model with home printers.

Digital imaging has made complete home imaging a possibility. Products are available such that any consumer can perform both image capture and image output in the home. With traditional film imaging, the output side was always provided in terms of a service via a photolab. Consumers now may choose to have digitally captured images printed via a service at a digital photolab or perform this function themselves with via a printer within their own home. Many other functions may be offered as either an in home product or an off-site service. It has been argued that service systems have environmental advantages over product systems, chiefly due to economies of scale, but does this hold true with consumer imaging? The larger question is whether a product service system a preferred strategy for sustainability.

1.4 Strategic Assessment

Despite desires to reduce the environmental impacts across various industries, realistically, change of any magnitude usually requires some amount of time. An example of a short range solution might be the reduction of environmental impacts in current processes by modifying procedures in order to recycle instead of landfill wastes. Altering business practices or system instantiation (such as service vs. product) would be a short to medium term tactic while the development of new, cleaner technology would be an example of a longer term solution.

Potential improvements when working with modifying existing processes in a short term basis are somewhat capped by the particulars of the processes involved. For example, while capturing, treating or diverting waste streams may help reduce environmental impacts; these afterthought type activities can only improve environmental performance so much. To get beyond this level of environmental performance will require more intensive modification to the processes which may include development of new technology. Applying existing technology in a different way, such as in a service system instead of a product system, may also provide some environmental benefits.

Of the range of activities that can help improve environmental performance, the development of new technology has the potential to provide the most benefit. Pursuit of this new technology, however, is not without risk and is usually more of a long term investment and thus may require a larger long range investment. Investigation of new technology alone, without attention to shorter term projects such as improving currently operating processes, ignores potential opportunities to reduce impacts on a closer horizon. This leaves a variety of options for those in a decision making role, especially for larger organizations. The question of which paths to choose is influenced by goals of the decision makers as well as the information at hand during the decision process.

Environmental issues are inherently multidisciplinary. They can be of local, regional or global concern. The time horizon involved can vary with different environmental problems. A businesses activity can have environmental affects outside of its own facilities related to both the upstream impacts due to materials and energy input used in such activities to downstream impacts associated with product use and end of life. These challenges require a broad perspective to ensure that the environmental impacts related to the entire life cycle of the products or processes are assessed.

With the environmental affects from industry gaining recognition as a common problem, many companies have developed environmental goals and publish environmental reports similar to their fiscal reports. While financial analysis tools and methods are well established, means of assessing environmental performance are still undergoing development and are far from agreed upon. However, it is important to give environmental issues consideration in decision making. So, how does a company evaluate strategic environmental performance issues with new and established business activities? Answering these questions requires a broad perspective, both in terms of impacts and life cycle of the product. Focusing on a single environmental issue for example can blind the decision makers to the myriad of other issues. Similarly, if they focus on only the "inside the fence" impacts in the use phase may be ignored. Life Cycle Assessment is one tool that can be used to address some of these issues.

1.5 LCA Introduction

In 2001, the International Standards Organization (ISO) published standards for Life Cycle Assessment (LCA)[2] as a tool for evaluation of environmental impacts. LCA has been used for a variety of applications in many different industries. These include assessing differences in computer display technologies[3], comparing different packaging scenarios for yogurt delivery[4] and in establishing a baseline for environmental performance of personal computers.[5] Internal studies at Kodak began in the late nineties and have covered a range of internal systems and products, many of which were leveraged for this study.

LCA is one way to evaluate impacts that has been standardized. However, it has high data requirements, therefore is most suitable to evaluating existing technologies, where a lot of information is known, rather than new technologies with some lacking information. Evaluating existing technologies and methods of instantiating these may provide a quicker means of reducing current impact versus developing new technologies. New ways of setting up business and moving towards a service scheme instead of a product scheme may help reduce impacts by sharing them across many consumers. Bringing these assessments into the consideration for strategic business questions may help to provide better decision support.

1.6 Thesis Structure

The assessment of the issues above leads to several questions regarding consumer imaging, product systems and strategic business decisions. These questions, as well as the hypothesis for each are summarized below.

Question 1 - Is there an environmentally preferred method of consumer imaging, is digital better than traditional imaging?

Hypothesis – From a brief comparison of digital and film imaging, film imaging uses photographic film and batteries as consumables while digital cameras only use batteries. Traditional processing and output systems are service systems; these systems, especially wholesale processing and printing facilities, employ economies of scale which may provide environmental as well as economic advantages. Lacking further information, the hypothesis for this question is that digital may have advantages over film capture and traditional processing and output may have advantages over digital processing and output.

Question 2 - Is a Product Service System an environmentally preferred strategy over product systems?

Hypothesis – The concept of economies of scale is one that has driven manufacturing since the Industrial Revolution. While economics is largely the force behind this phenomenon, the efficiency benefits, especially in resource use, seem to suggest that a service oriented system may also have environmental benefits. A product-service system thus is hypothesized to be a preferred environmental strategy.

Question 3 - How does a company evaluate strategic environmental performance issues with new and established business activities?

Hypothesis – Strategic performance issues involve both a wide perspective of issues as well as a broad view of the systems life cycle. The use of LCA as a tool to provide information about these systems offers both a broad life cycle perspective and a wide range of environmental impact results. Therefore, it is hypothesized that LCA is a good approach to provide information for strategic decisions.

With these questions in mind, the structure of the work in this thesis follows. This chapter, the introduction, provides some background and motivation for the questions addressed in later sections. Following the introduction, chapter two provides a literature review of previous work that relates to these questions. After this review, a methodology is developed and related in chapter three, with the results provided in chapter four. Finally, the conclusions from the work, as well as closure to the questions and information regarding future work are explored in the fifth chapter. The graphic below serves as an overview of this structure.

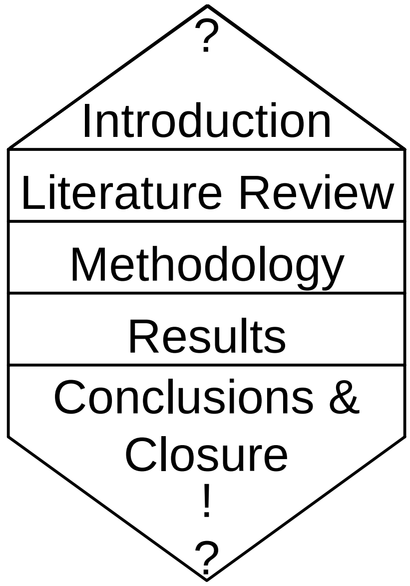

Figure 5: Thesis structure

CHAPTER 2 - BACKGROUND

A literature review was completed with two goals in mind. The first was to identify established standards and practices for LCA. The second was to find previous studies that are related to three questions posed in the first chapter. To this end, the first section of this chapter is focused on the general aspects of LCA and a bit of the tools history. Next the standards and practices established by the International Standards Organization (ISO) while the last section details previous research related to the three questions. After this review a methodology for approaching the research questions is developed in the third section.

2.1 Life Cycle Assessment Background

Life Cycle Assessment (LCA) is a tool which helps to analyze the energy consumption, raw material consumption, different types of emissions and other factors over a product's life cycle and attempts to assign environmental impacts to these various product stages. LCA is a tool developed to help evaluate the environmental impacts related to a specific product. As its name implies, LCA is involved with the entire product's life cycle. Shown in the figure below, this perspective allows the inclusion aspects of the product life cycle not normally assessed; specifically areas of the product's life cycle that are "outside the gates" of an organization. Additionally, LCA focuses on a per product or service environmental impact assessment. Evaluating the impacts on a product basis facilitates a relation of environmental impacts with the end product or service that the customer is receiving. While these special perspectives provide valuable insight into environmental impacts, they also incorporate challenges in terms of data acquisition and interpretation of results.

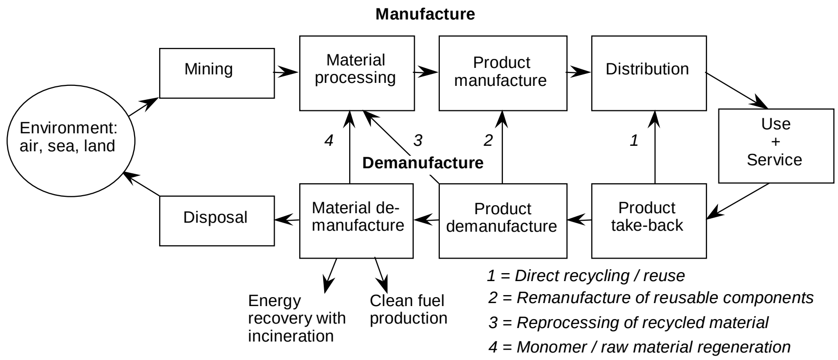

Figure 6: Life cycle of a product (Bras 1997)[6]

LCA has its roots in the energy analysis techniques developed in the 1960s and 70s. While these quantitative assessment methods originally focused on energy systems, over the years additional methods have been developed in order to broaden the assessment to include a myriad of issues. One of the first multi-criteria studies was done for Coca-Cola and compared plastic with glass bottles. In the early nineties development of LCA methodology and practice continued with effort from corporations, academia and organizations such as the Society for Environmental Toxicology and Chemistry(SETAC) and the Society for Promotion of Life-cycle Assessment Development (SPOLD). LCA was recognized and formalized by the International Standards Organization (ISO) in 2001.

2.2 ISO Life Cycle Assessment Standards

ISO Environmental Management standardized LCA in four documents; ISO 14040, 14041, 14042 and 14043.[7] These documents describe the framework and outline the sections of an LCA. They also mandate certain elements that should be included in an LCA, especially one that seeks to make competitive assertions to the public. The first standard, 14040, defines the principles and framework of LCA, defining important concepts and providing some base for the other documents to provide the details of the different portions of the assessment.

2.2.1 14040 Life Cycle Assessment – Principles and Framework

This document defines LCA and identifies what types of organizations might apply it and to what ends. Included in potential applications are identifying opportunities for improvement, as an aid for decision making, strategic planning, setting priorities and process or product design. Suggested organizations that might apply LCA for these reasons include industry, governmental and non-governmental organizations.

One key aspect of understanding tools is the understanding of their limitations. This first standard identifies some of the limitations in LCA. These limitations are due to either the inherent restrictions of LCA or some potential problem in application of the LCA methodology. Many of the identified limitations have to do with imperfect data, such as data availability, accuracy of data and the potential for incomplete aspects of the data such as spatial and temporal dimensions. Models of the systems of interest are limited by the data available and the assumptions made in developing the model. These data related limitations can be aggravated by the choices and assumptions that one is required to make in order to move ahead with imperfect data. The choices and assumptions can be subjective and can thus introduce some unintended bias in the study.

After the scope of LCA and its limitations have been established, ISO 14040 goes on to outline the methodological framework for the study itself. This framework is also useful as an outline of the remaining standard documents. The standard provides definitions and a general description of LCA including its key features. One of these key features is the structure of LCA, divided into phases. These phases include goal & scope definition, inventory analysis, impact assessment and improvement assessment. The standard details some characteristics of these different phases of the study which provides the outline for the later standards.

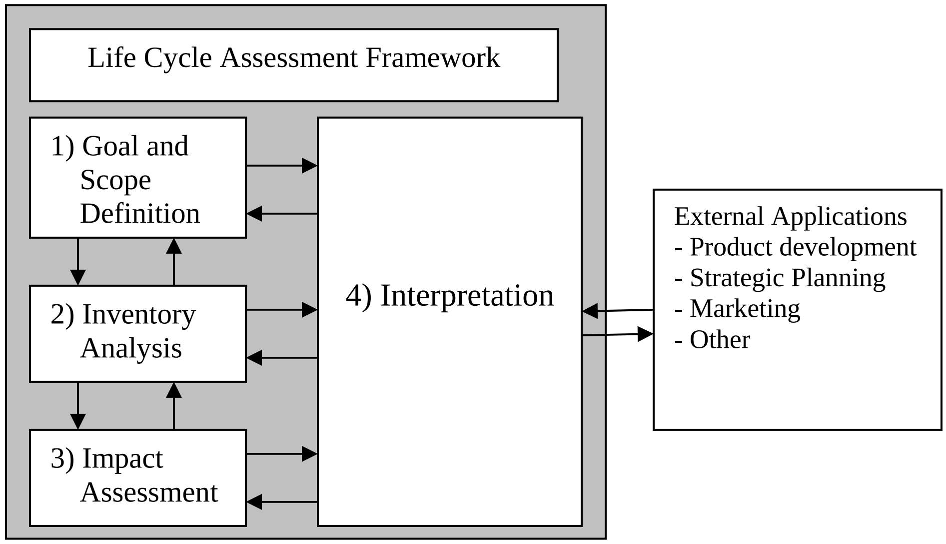

Figure 7: Life cycle assessment framework

Finally, ISO 14040 provides guidelines and rules for reporting and critical review. Reporting formats can vary, the standard mandates that the type and format of the report should be defined during the study's scope phase. Critical review however is mandated for any LCA that is to be publicly disclosed, such as some sort of comparative assessment to be used in a marketing claim. These reviews are to include internal and external expert review along with a review by an independent panel.

2.2.2 14041 Life Cycle Assessment – Goal & Scope Definition and Inventory Analysis

This standard provides the details of the first two phases of LCA that were introduced in the previous standard, Goal and Scope Definition and Inventory Analysis. It includes definitions of the components of these phases along with structure and suggested procedures for performing the assessment phases. General concepts of life cycle inventory analysis and goal and scope definitions are also introduced.

The concept of a product system which is built from unit processes is the foundation of the life cycle inventory analysis. These unit processes have elementary flows in from the environment and out to the environment and they are the basic units of the product system models. Categories are suggested for elementary flows data but they are not mandated and additional categories may be specified by an individual study's goal and scoping documents. The modeling of the product system itself is also addressed the assumptions, limits and simplifications made to the product systems model, for the sake of practicality, must relate to the goal and scope stated in the study and should be transparent.

The first phase of an LCA study is that of defining the goal and scope. The goal is said to define the application and motives and the audience. A study's scope is to identify the core functions of the product system, its functional unit, reference flow and system boundaries, amongst other things.

The functional unit defines a quantity for the product systems function. This is a relative measure that the life cycle inventory data is associated with. The reference flow is the amount of the defined products required to fulfill the function. Initial system boundaries identify the borders of the study from the perspective of the studies goal. These boundaries may change during the process of gathering data as more is learned about the systems under study. The life cycle stages are also defined in this phase of the study. These life cycle stages partition the data that is collected in order to represent the life cycle of the product system.

The standard describes some data categories that are used to identify the inflows and outflows and their source or media of transport, such as energy resource or emission to air. Criteria are recommended by the standard to guide the data gathering. These criteria as well as data quality requirements provide some guidance to what to include, what to exclude and when the data for a particular process can be considered complete.

One of the important themes in these standards is that performing an LCA is an iterative process and the structure for the study may change as data and process models are developed. Thus, the scope and potentially the goal may be modified as these changes occur throughout the study. Additionally, once the results have been achieved, an assessment of these results against the goal and scope of the study needs to be completed in order to determine what conclusions can be made within the goal and scope framework. Sensitivity analysis on the assumptions key to the study and results is critical to this assessment.

In addition to detailing some of the aspects of the first phase of LCA, goal and scope definition, this standard provides an outline of the procedures for performing life cycle inventory analysis. This outline begins with an overview of the entire process followed with details relating to each step in the inventory. Data collection procedures are the first stage, followed by calculation procedures, validation assessments, allocations and interpreting LCI results.

Data collection procedures begin with guidelines for the preparation work which include drawing diagrams and describing the unit processes, identifying the units of measure and provisions for reporting irregularities. The descriptions of data collection techniques as well as calculation techniques for each data category are also included in this section of the standard. It also advises to document the data collection procedures and describe the processes and calculation procedures clearly to steer clear of duplicate entries, gaps in the data sets and to ensure consistency. The standard also comments on the validation of the data proposing the use of mass and energy balances or other comparative analyses. During this development of data for unit processes the data must be related to the unit product output for each of the unit processes in order to finally relate the data to the functional unit of the study.

During the collection of data in the LCI there may be some processes that require some allocations made to the flows due to processes that are not reducible to a clean one product process with simple inputs. In this case, allocation is required to assign data to a particular to the appropriate shared process. While provision is given to deal with allocation, the initial step suggested in the standard when approaching this problem is avoidance. If a process cannot be broken down into two or more unit processes to avoid allocation, then the allocation should be based on some physical relationship such as mass flow for the two outputs or, when physical relationship is not possible, then some other relationship such as an economic one should be used.

Finally the ISO standard 14041 covers some of the limitations of LCI, interpreting the results and reporting the results. A review is required of the studies initial goal and scope as well as the critical characteristics and quantities that were defined in the first LCA phase such as the system functions, functional unit and system boundaries. Further limits in the interpretation of the LCI results that are described include the warning that LCI results are simple inflows and outflows and not directly related to environmental impacts yet. Data uncertainty is also of concern during this stage and data quality tools such as sensitivity analysis are suggested as tools that should be used to assist with the interpretation of the LCI results. As far as reporting, the standard provides a general report outline along with identification of which of the outlines elements should be included in a third-party report.

2.2.3 14042 Life Cycle Assessment – Life Cycle Impact Assessment

The third standard related to LCA describes the third phase in LCA, Impact Assessment. This standard includes a general description of impact assessment as well as its mandatory and optional elements. The standard concludes with comments on the limitations of LCA, details about reporting and critical review of studies.

This impact assessment phase is described by the standard as connecting the inventory to the impact to provide a view of the environmental impacts. This connection is done by assigning the life cycle inventory results into impact categories and aggregating these category results to achieve a final impact assessment value per impact category. These impacts are related to the functional unit of the study for comparison between different product systems, life cycle phases or other aspects of the product system.

The mandatory elements itemized in the standard include, selection of impact categories, indicators and characterization models followed by assignment of LCI results and the calculation of each indicator category results based on the characterization models and the LCI results. Optional elements follow these mandatory ones and include normalization, grouping related impacts together, weighting of the impacts and data quality analysis. Three specific techniques for data quality analysis are introduced in the standard, gravity analysis, uncertainty analysis and sensitivity analysis; the use of these techniques is dependent on the studies goals.

The standard concludes with comments regarding the limitation of impact assessment, publicized comparative assertions, reporting and critical review. Limitations of impact assessment identified by the standard include a lack of consideration of complete set environmental issues, subjectivity introduced by value choices throughout the study. Additionally the standard points out further limitations from the lack of consideration for spatial and temporal aspects of the impacts and the exclusion of actual impacts on the category endpoints and actual environmental affects.

The final comments from this standard are focused on rules for public comparative assertions, reporting and critical review. Rules for critical review include a prohibition on weighting during the impact assessment phase and the inclusion of a comprehensive set of category indicators as well as data quality assessments. The standard provides an outline of reporting contents for different circumstances in the development of an impact assessment along with detail requirements for critical reviewing of the assessment.

2.2.4 14043 Life Cycle Assessment – Life Cycle Interpretation

This last standard, ISO 14043, provides an overview of the final phase of LCA, life cycle interpretation. It states several objectives for life cycle interpretation, including, analysis of the results and subsequent development of conclusions, limitations and recommendations based on these results. Life cycle interpretation includes identification of significant issues, evaluation of the study for completeness and consistency as well as conclusions and reporting on significant issues.

For the first step, identifying significant issues, the standard identifies four types of information required from the earlier LCA stages. These four types are the results from the inventory analysis and impact assessment stages, the methodological choices, the value choices and the roles and responsibilities of those involved in the studies. Finally, the results from any critical review process that may have been undertaken are required. Significant issues can be inventory parameters, impact indicators, specific life cycle stages or unit processes.

The standard details the evaluation of the results in several steps and it's objective of establishing an idea of the quality of the results. Three steps are included in the standard for this evaluation: completeness check, sensitivity check and a consistency check. The completeness check evaluates the LCA for missing or incomplete information that may influence the results. Sensitivity check evaluates the results are unduly influenced due to the uncertainty of the data. Finally, the consistency check assesses differences in the data quality between various product systems or life cycle phases.

The final section of this standard guides the development and reporting of conclusions and recommendations. The development of these suggestions from the analysis of the LCA is an iterative process, according to the standard. This process begins with identifying the significant environmental issues from the results and evaluating the methodology for achieving these results. Preliminary conclusions are to be compared to the rules outlined in the goal and scope section of the study. If these conclusions and recommendations are consistent with the rules, then they are reported. If they are not consistent, the standard suggests returning to the initial step and refining the study.

2.3 Imaging Related LCA Applications

Life Cycle Assessment has been used in a variety of applications for a variety of reasons. The systems analyzed range from the production of computers[8], automobiles[9] or electronics[10] to manufacture process design.[11] The applications vary from providing feedback to product designers[12] to comparing alternatives that provide the same or very similar functions.[13] This review will focus on the different aspects that are involved in this study. Applications that are considered here are consumer imaging systems, their support and related systems such as computers. Additionally, studies involving the product service systems comparisons to traditional product systems and strategic life cycle assessments are considered in this review.

Imaging Systems

In a study published in 2000, Yang, Luo and Zhou consider a fuzzy logic life cycle assessment model for the comparison of digital cameras and film cameras.[14] This comparison took into account not only environmental impacts, but also performance characteristics and economic costs. The case study includes the comparison of three digital cameras and three film cameras. The results from a life cycle assessment of the each of the cameras are used as the environmental burden score in the fuzzy logic assessment of the aspects of camera performance which also includes cost factors and performance factors. In a brief review of LCA methodology, the authors note two main drawbacks that exist in existing LCA approaches. The first drawback the authors note is the challenge of data collection and output assessment. This challenge exists in many activities, but it is magnified by the quantity and type of data required by LCA. This fuzzy logic method is aimed at assisting with this first drawback. The second drawback that is mentioned in the paper is that current LCA methods are "limited to a single life cycle." The authors note that others are exploring concepts of "multi-lifecycle assessment methodologies."

The authors provide some background for fuzzy logic in the paper. This background information includes what type of data inaccuracies or imprecision can be handled by fuzzy methods. These types of data include that which is "imprecise because of incomplete or non-obtainable information" and "linguistic terms." These types of data are incompatible with traditional probability based statistical tools; the linguistic terms may contribute additional problems to the analysis. Specifically they are subjectively defined. If assessments of this type are pursued, care should be taken in assigning subjective values to a category that can, with a little more effort, be defined quantitatively and objectively. It is a balancing act between ease of analysis and objectivity of analysis. Additionally the multi-criteria assessment function involves weighting the criterion. This is, perhaps, typical of such methods, but it is important which and how these criterion are weighted, as will be seen further down the line.

The description of the case study begins with a description of the collection of the data. Understood from the earlier abstract and introduction sections is that this method is one of comparison between film cameras and digital cameras on the given criteria; environmental performance, cost and picture quality. The data collection does not seem to be rigorous but as the authors say, "the results are more significant from the point of demonstrating the assessment methods than judging the merits of the cameras cited here." Additionally, it is not clear that the supporting systems, such as processing equipment, are included in the assessment. The demonstration of utilizing fuzzy logic may be valuable to assess whether such an approach may be useful. The determining factor involved in deciding if and how to use fuzzy methods, it seems, is the goal of the activity, target audience of the report and how such a report will be used.

While this study demonstrates an interesting technique for the comparison of systems, the inclusion of the economic and performance indicators and the lack of inclusion of imaging support systems hamper direct comparison of the systems environmental results. Additionally, in light of the authors caution regarding the quality of the life cycle assessment data, the results themselves cannot be considered in the attempt to answer the question regarding environmental performance of cameras. Although direct comparison or consideration of the fuzzy logic study's results may not be appropriate, some reflection on the issues that were exposed by it may be useful. Specifically, the importance of the differences in the quantities of energy use, solid waste and chemical waste are of note. Further explorations of image processing and output systems are required for a complete picture of the imaging chain.

Computers & Support Systems

In 1997, Tekawa, Miyamoto and Inaba published a report on an LCA comparison between a desktop PC and a laptop PC.[15] Four impact categories were assessed in this study; greenhouse effect, acidification, eutrophication and resource consumption. Their comparison found the environmental loads from PCs were highest in the use and production stages. This PC utilized a CRT display while the laptop computer used an LCD display. In the life cycle phases, production, circulation use and disposal, the desktop PCs had the highest impacts. For both computers, the use and production phases dominated the impacts. Electricity use was the source for environmental impacts in the use phase, and since the desktop PC and CRT screen had the larger power requirements; it of course had a higher impacts than the laptop PC. Recommendations generated from this study included four items. First reduction of power consumption, since use phase is the most dominant driver for use phase impacts. Also included in the recommendations were utilizing LCD monitors for desktop PCs, improving the PWB assembly process and utilizing plastic materials in the computer housing.

The US EPA and the University of Tennessee published a report on their work assessing the environmental life cycle impacts for computer displays in December of 2001.[16] This study evaluated the environmental impacts of both liquid crystal display (LCD) and cathode ray tube (CRT) monitors. The geographical boundaries for this study included the United States market for the use and end of life phases and worldwide boundaries for the, manufacturing, material processing and mining phases. Packaging and distribution were not included due to data irregularities and unavailability.

It is noted in this report that LCD monitors use less energy during the use phase than CRT monitors but their upstream energy usage may be more. In the results presentation, the CRT monitors score higher in most impacts, including air emissions, water pollutants and other solid wastes. LCD monitors score higher only than CRT monitors in wastewater. Sensitivity analysis performed for the two systems indicated CRT monitor results are most sensitive to glass manufacturing energy use while LCD monitors are sensitive to lifetime assumptions. Even with the variation of glass production energy use for CRT monitors, however, the LCD monitor tended to perform better. While this report was not undertaken with the goal of creating comparative assertions, the results do show that LCD monitors do perform better in more of the impact categories than CRT monitors.

Inkjet printers represent part of the proposed imaging output system. A paper from Hewlett-Packard and Ecobalance addresses the environmental impacts from the inkjet printer cartridge.[17] The life cycle phases in this paper break down to printhead manufacturing, final assembly, distribution, use and end of life. Impact categories included natural resource depletion, global warming potential, acidification potential and nitrification potential. Results for the different phases rank final assembly as the highest in all categories, followed by printhead manufacturing, distribution and finally end of life. A comparison of the print cartridge with other printing impacts showed paper production dominating both printer electricity and cartridge impacts.

The European Union and Atlantic consulting completed a study of personal computers in 1998 for the EU Ecolabel scheme. This study was intended to be an investigational study focusing on the product group of personal computers with the intent of determining the potential for developing an Ecolabel for the product group. This work identified the use stage as responsible for major impacts. The results from this study indicate the use stage dominates emissions, energy consumption and waste generation with materials production ranking as highest in resource consumption. Improvement suggestions favored use phase modifications such as extended lifetime and energy efficiency over recycling and lead-free solder.

Related LCA Studies

One of the interesting aspects of a comparison between traditional film cameras and digital cameras is the idea of a comparison between a traditional material process and that of a digital process. This shift from a more material or analog based systems has been seen in most media forms. From audio to still pictures and video technology has been introduced that competes with many of the traditional media. An interesting study related to this transition was performed by Kozak in 2003.[18] This study examined the difference in environmental performance between print and electronic books. The focus was on a comparison of scholarly literature via print versus digital media. While this study focused on electronic textbooks, it does relate to this consumer imaging question in that it compares physical instantiation to a digital one.

This study divides life cycle stages into five distinct phases; material production, manufacturing, distribution, use, and end-of-life. For traditional books, the upstream impacts dominated the impact results, while use phase dominated the impacts related to the electronic reader and its energy use. Use phase assumptions were extremely important to the results with a higher amount of use per physical book helping reduce the total impact per book and the higher amount of use per electronic book generating more impact. While this study focuses on images rather than print, results for imaging are expected to parallel this print study.

Product Service Systems

In 2000, Oksana Mont with the International Institute of Industrial Environmental Economics at Lund University published a report on product service systems.[19] In this report the several important conclusions were drawn. One of the more important conclusions was that the environmental implications of product service systems were not thoroughly investigated. Additionally two interesting phenomenon were proposed in this report. The first being the social changes of shifting to a service system includes the potential for increased employment due to a more labor intensive process. Additionally, a rebound effect was suggested due to the economic advantages of service systems. This rebound effect was related to the idea that a consumer who spends less on a service system will thus have more disposable income to spend on some other product or service that would incur extra impact that would not have occurred if the consumer had selected a product system to satisfy the original function. These conclusions highlight the importance of assessing consumer behavior in addition to evaluating the performance of technical systems.

Other important concepts identified in this report include the idea of a functional economy. This functional economy is based on the idea that consumers end goal is not the products themselves, but the functions that these products provide them with. With this understanding the door to a transition towards service systems is open. Product service systems are suggested to provide the same or very similar functions to product systems but with increased environmental impacts. This environmental performance seems to be mostly related to the benefits gained through economies of scale and sharing resources.

2.4 Literature Review Summary

The first goal of this literature review was to identify the standards and practices for LCA. The ISO series of standards regarding LCA provided these internationally recognized descriptions of and practices for the use of the tool. The second goal was to identify and review previous studies and papers that are related to the subject matter of this study. A variety of studies were reviewed that related to not only consumer imaging, but also to the support systems for these activities and relating to product service systems.

The ISO 14000 series of standards, specifically 14040, 14041, 14042 and 14043, defined not only the structure of LCA activities but also provided guidelines and methodology for the tool. The first standard, 14040, established the principles and framework of the study. The phases of LCA, goal and scope definition, inventory analysis, impact assessment and improvement assessment are also introduced in this standard. Potential applications are also suggested; including identifying opportunities for improvement, aid for comparative assertions, decision making, strategic planning, setting priorities and process or product design. This lends credence to the concept of using LCA in an attempt to explore the three questions introduced at the end of chapter one. Specifically, question one involves comparing technologies while question two is involved with a comparison of business strategies (product systems compared to product service systems) and question three relates to using LCA to assist with strategic business issues.

Finally, some of the limitations of LCA are discussed. Many of the identified limitations have to do with imperfect data, such as data availability, accuracy of data and the potential for incomplete aspects of the data such as spatial and temporal dimensions. Models of the systems of interest are limited by the data available and the assumptions made in developing the model. Tracking assumptions and determining their influence on the results is recognized as critical to understanding the studies results.

The second standard in this series, 14041, details the first two phases in LCA, goal and scope definition and inventory analysis. The goal of the study defines the application and motivations of the study. These are defined in the first chapter in the three questions which are the focus of this study. The studies scope is to identify the core functions of the product system, its functional unit and system boundaries, amongst other things. The functional unit defines a quantity for the product systems function. This is a relative measure that the life cycle inventory data is associated with and the functional unit for this study is further defined in the third chapter. The system boundaries and life cycle stages are also further defined in the third chapter. Additionally, once the results have been achieved, an assessment of these results against the goal and scope of the study needs to be completed in order to determine what conclusions can be made within the goal and scope framework. Sensitivity analysis on the assumptions key to the study and results is critical to this assessment.

ISO 14042, the third in the series of LCA standards, provides details about the third phase of LCA, life cycle impact assessment. This phase of LCA connects the inventory to the impact to provide a view of the environmental impacts. This connection is done by assigning the life cycle inventory results into impact categories and aggregating these category results to achieve a final impact assessment value per impact category. These impacts are related to the functional unit of the study for comparison between different product systems, life cycle phases or other aspects of the product system. The mandatory elements itemized in the standard include: selection of impact categories, indicators and characterization models, assignment of LCI results and the calculation of each indicator category results based on the characterization models and the LCI results. There are two of the optional elements mentioned in the standard that are included in this study. The first is normalization, which is employed to protect some proprietary information. In addition, sensitivity analysis is done to explore the influence of the assumptions on the results.

The fourth standard in the series focusing on LCA, 14043, the fourth phase of LCA, life cycle interpretation, is defined. This phase of LCA is where the practitioners develop conclusions from the results of the study. These conclusions can include determining the significant issues such as inventory parameters, impact indicators, specific life cycle stages or unit processes. Based on these conclusions, recommendations can be made to improve the environmental performance of the systems under investigation.

The second goal for this review was to find previous studies that are related to three questions posed in the first chapter. To this end, studies related to imaging systems and those systems that support them were investigated. These studies include not only digital and film imaging systems, but also, computers, printers and support systems for these activities. Additionally information related to product service systems and product systems was investigated.

The first study related to imaging is a comparison of digital and film cameras. This comparison includes economic and functional performance indices and utilizes fuzzy logic in order to attempt to mitigate some of the challenges with LCA presented in data collection and output assessment. The data collection does not seem to be rigorous and is not clear that the supporting systems, such as processing equipment, are included in the assessment. While this study demonstrates an interesting technique for the comparison of systems, the inclusion of the economic and performance indicators and the lack of inclusion of imaging support systems hamper direct comparison of the systems environmental results.

In the computer and support system review there are several issues that are identified in many of the studies that are of interest to this study. While many of the studies used different environmental impact indicators, there are some similarities in the reports that are related to this study. In the majority of studies, the life cycle phases that scored highest in impact are the use phase and the upstream phases. Furthermore, energy use was targeted in several of the studies as a primary driver of impacts and an area for improvement.

The final report that was examined was related to product service systems. This report suggested that a product service system might have environmental benefits but they have not been rigorously studied. The report suggested two potential affects related to these systems. The first was an increased level of employment due to a service oriented economy and the second was a rebound effect due to surplus consumer income due to economic benefit of service systems being used for additional services.

This review of previous studies provides several insights that can be related to this study. The first half of the review identified the structures and procedures of LCA from the ISO standards. The second half examined previous studies that are related to this one and identified several issues of importance. First the relative weight of the upstream and use life cycle phases in many of the results provides some suggestion as to the results that this study may provide. The importance of energy is also noted in several of the application studies and is highlighted in this study as an environmental aspect of interest. Finally the issues relating to product service systems were introduced.

CHAPTER 3 - METHODOLOGY

3.1 LCA Development

LCA, as with some other analysis techniques, is data driven. With LCA however, the data not only controls the conclusions one can make, but it also can influence the structure and scope of the analysis. Leveraging existing data and past studies was a necessity for this study due to the broad range of systems under investigation. However, incorporating past studies and data provides not only benefits but also brings restrictions due to the structure, scope and completeness of these sources. This particular study investigates multiple processes related to consumer imaging. With the various processes and products investigated, a wide variety of data sources was required. These different data sources were organized in a fashion as to be useful in the assessment. A hierarchy of the different data was created. This hierarchy starts at the top with the consumer imaging scenarios, under which are imaging stage process models and finally LCA modules. These imaging scenarios along with their capture, processing and output processes are contained in the table below.

Imaging Scenarios	ABBR	Capture	Processing	Output
Film Capture to Retail Print	FC/R	Film	Retail	Retail
Film Capture to Wholesale Print	FC/W	Film	Wholesale	Wholesale
Digital Capture to CRT Retail Print	DC/CR	Digital	PC/CRT	Retail
Digital Capture to LCD Retail Print	DC/LR	Digital	PC/LCD	Retail
Digital Capture to CRT Wholesale Print	DC/CW	Digital	PC/CRT	Wholesale
Digital Capture to LCD Wholesale Print	DC/LW	Digital	PC/LCD	Wholesale
Digital Capture to CRT Inkjet Print	DC/CI	Digital	PC/CRT	PC / CRT Inkjet
Digital Capture to LCD Inkjet Print	DC/LI	Digital	PC/LCD	PC / LCD Inkjet
Digital Capture to Display CRT	DC/CD	Digital	PC/CRT	PC / CRT Display
Digital Capture to Display LCD	DC/LD	Digital	PC/LCD	PC / LCD Display

Table 1: Consumer imaging scenarios

The imaging scenarios represent ten different pathways that consumers can choose from in order to provide the imaging functions, capture, processing and output. These scenarios include two entirely traditional scenarios, four entirely digital scenarios and four hybrid scenarios. These scenarios each contain three types processes; one image capture process, one image processing process and one image output process. There are twelve of these imaging processes. In image capture there are two capture processes, film and digital. Image processing has four processes, retail, wholesale, PC processing with a CRT display and PC processing with an LCD display. The final stage, image output includes six processes, retail, wholesale, inkjet out via a PC with a CRT or LCD display and display via a PC with a CRT or LCD monitor.

These process models embody one of the main consumer imaging processes that are utilized in imaging. The imaging stage process models were comprised of one or more LCA modules. These modules are potentially stand-alone product or process LCAs. They are incorporated into the imaging stage LCA to complete that stages process LCA. These LCA modules had a variety of sources that can be broken down into three types: external reports, internal studies & product teardowns.

External reports were perhaps the quickest means of obtaining LCA data, but they also incorporate the most restrictions in their use. Internal studies provide the most flexibility in terms of scope and structure, but with the cost of being the most time intensive. Product teardowns linked with an LCA database provide a relatively quick means of obtaining LCA data. The use phase can be closely studied before product teardown and assessment of the materials in the product during the teardown can help define the end of life. Product and packaging details linked with LCA database entries provide only a partial picture of the systems upstream phases because these upstream impacts are entirely reliant on general database entries. The figure below summarizes the processes that were selected, based on data availability and how these LCA processes were developed.

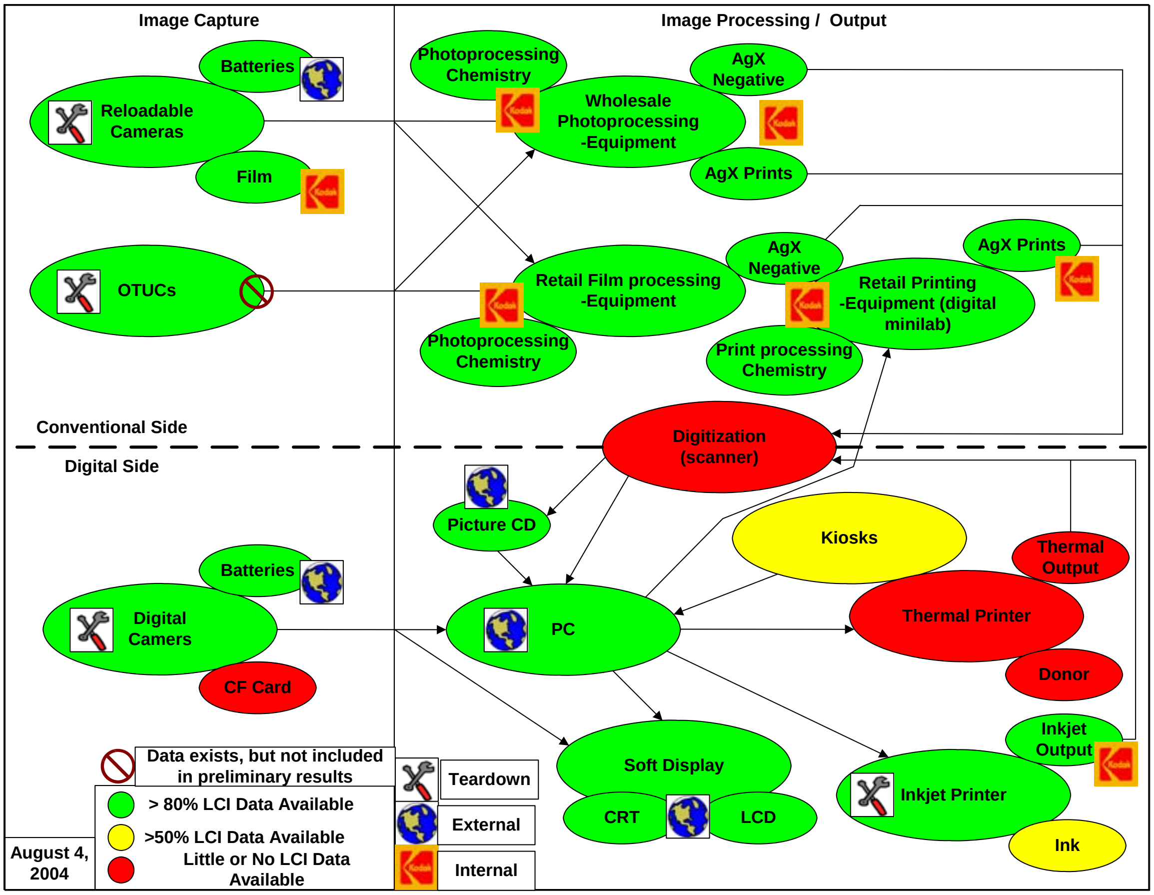

Figure 8: Consumer imaging process tree

The resulting effects of including data from different sources can be seen in the structure of this LCA. The life cycle phases, for example, were limited to the lowest common denominator from the incorporated data. Specifically the mining, material processing & manufacturing stages were aggregated into one phase called "upstream." This was required for comparability between imaging stages and scenarios as well as for specific LCA modules to be used in building the image stage process models required for the selected scenarios.

While the data sources did influence the scope and the structure of the study, it was also guided by ISO standards for LCA in ISO 14040-3. The structure of the study, its progression and definition of goals as well as impacts and improvement assessments were guided by the ISO standards.

3.2 Goal & Scope

3.2.1 Study Goals

The initial goal of this project was to provide a quantitative profile of the environmental impacts, and their drivers, for each life cycle stage of different imaging systems. This study was to help establish a baseline for resource consumption, energy use and environmental impact information. Providing this profile of the environmental impacts for the various life cycle stages of the systems involved would help identify life cycle stages where improvements could be made.

Initially, only a select sub-set of imaging systems was planned to be analyzed, with the intent to expand to additional systems. The analysis was to be conducted in such a way as to be useful / leveraged across various imaging applications and to be consistent with industry practice and ISO standards.

Upon further exploration of the subject matter, several other relevant issues were identified that went beyond a simple question of comparing different systems. There are implications for exploring the ideas of Product Service Systems as well as evaluating strategic level environmental issues. These three core areas are expressed formally in the three questions identified in the introduction.

Table of Goals	
1.	Provide a quantitative profile of environmental impacts
2.	Provide a quantitative profile of the impact drivers
3.	Establish a baseline for resource consumption, energy use and environmental impact information
4.	Identify areas life cycle stages where improvements can be made
5.	Maintain openness necessary to expand to additional systems and various imaging applications
6.	Be consistent with industry practice and ISO standards

Table 2: Table of goals

3.2.2 System Descriptions, Imaging Stages

With the goals of the study established, a more formal definition of what products and processes are to be studied is due. Imaging processes can be divided into three stages: image capture, image processing and image output. Image capture involves the operations required to store a particular image to an intermediate storage media. Image processing is the intermediate step required to prepare the captured image for printing. In traditional photography this means film developing, fixing and washing the film. The final stage in imaging is that of image output, reproducing the original captured image on the selected output media. Although these stages are clearly tied to traditional film imaging, parallels do exist in the newer digital processes. Capture and printing are clearly the same activities in both traditional and digital imaging; however, the lines of where image processing begins and ends are a bit less well defined. In this study, the digital image processing stage was defined to be the transfer of an image from a digital camera to a PC and then to the output system.

The concept of imaging processes was taken a bit further in the development of the actual LCA models. Each of the major imaging stages were developed from a process philosophy rather than a product philosophy. Some of the reasoning for this is tied to the facilitation of the functional unit of the study which will be discussed later. This process philosophy ties the function of the desired process to the impacts rather than linking a specific product to the impacts. The result of this was the twelve different imaging stage process models that were developed for this study. Each of these process models falls into one of the imaging stages, as shown in the table below. There are two capture process models, four processing models and six output modules. These different capture models were then combined to create ten different consumer imaging scenarios based on the options available to consumers.

Stage	Process	Abbreviation
Capture	Film	FC
	Digital	DC
Processing	Retail	RFP
	Wholesale	WFP
	Digital PC/CRT	CRTP
	Digital PC/LCD	LCDP
Output	Retail	RP
	Wholesale	WP
	Digital PC/CRT Inkjet	CRTIO
	Digital PC/LCD Inkjet	LCDIO
	Digital PC/CRT Display	CRTD
	Digital PC/LCD Display	LCDD

Table 3: Imaging stages

Each of the imaging stage models are a combination of one or more LCA modules. In turn, each LCA Module represents a product and/or service system that helps achieve one or more of the imaging stages.

In image capture two distinct product systems were assessed. The traditional film capture system involved a reloadable flash film camera. The digital capture system assessed was a typical midrange digital camera. In the image processing stage, retail and wholesale film processing were modeled for the traditional side. Digital processing includes processing via a personal computer with either an LCD monitor or a CRT monitor. For the image output stage, retail and wholesale printing fill out the traditional side while digital output includes inkjet printing and display with an LCD computer monitor or a CRT computer monitor. The study was undertaken from a functional capability point of view and actual usage habits (especially with respect to the digital side) significantly change the results.

There are clear delineations between two primary technologies in the different imaging processes, traditional film based imaging and the newer digital imaging. LCA has been used in the past for comparative assessment of two competing technologies.[20] Additionally, there are different means of instantiating these technologies in different business models. Traditional film photography was established and succeeded as a product-service system. Digital systems have been marketed in both product only systems as well as product-service systems. Some have suggested these product-service systems may have inherent advantages in terms of environmental performance.[21] This study uses LCA to assess several of the consumer options with the given scenarios that explore the different methods of providing the imaging function.

Image Capture

The first process involved in consumer imaging is that of image capture. This process involves the recording of an image to an intermediate storage system. The two processes assessed for this study were film capture and digital capture. Film capture process involves image capture via a reloadable film camera. The primary artifact associated with this process is that of the camera itself. Consumables include photographic film and AA alkaline batteries. The function of the process is that of capturing one image for later output. The digital capture process involves image capture via a digital camera. The primary product associated with this process is that of the camera itself. Consumables include AA alkaline batteries. The function of the process is that of capturing one image for later output.

Image Processing

Retail processing is one of two traditional film processing options. The primary product is the retail processing equipment. The consumables include retail chemicals and utilities, in the form of water and electricity. The function of the process itself is that of processing the film for one image captured and preparing it for printing. Retail processing operations are usually located at drugstores or smaller photography shops in the United States and usually provide relatively speedy processing and printing (sometimes one hour photographs).

Wholesale processing is the second of two traditional film processing options, the primary product of this process model is the wholesale processing equipment. Like the Retail processing system, the consumables include wholesale chemicals as well as utilities. Again, the function of the process is the processing of the film for one image captured and preparing for printing. Wholesale processing and printing systems are designed to serve a larger region than their retail counterparts. They are usually overnight services at chain stores that feed film from a larger geographical region to a central location for processing and printing of photographs.

Digital processing via a PC with a CRT monitor is the digital equivalent of film processing, this process uploads the captured image data from the camera to the personal computer equipped with a CRT monitor. The primary equipment is the computer and monitor itself and the consumable is simply the electricity required for operation. Digital processing via a PC with an LCD monitor is exactly the same as the Digital PC/CRT except that the CRT monitor is replaced with an LCD monitor.

Image Output

Retail printing is the second half of the traditional retail photographic lab process. It involves printing an image that has been thus far captured and processed. The primary product is the retail processing equipment. The consumables include retail chemicals, photographic paper and utilities, in the form of water and electricity. A four by six inch print is the output of this process.

Wholesale printing is analogous to retail printing in that it is the wholesale version of the retail printing operation. It's primary product and consumables are thus similar, the primary product is the wholesale processing equipment while the consumables include wholesale chemicals, photographic paper and utilities, in the form of water and electricity.

Digital inkjet printing via a PC with a CRT monitor is the first digitial output option. The primary products are the PC and inkjet printer. The consumables are electricity, paper and inkjet cartridges. A four by six inch print is the output of this process. Digital inkjet printing via a PC with an LCD monitor is exactly the same as the Digital PC/CRT Inkjet except that the CRT monitor is replaced with an LCD monitor.

The capability of the personal computer to display digital images led to the inclusion of the digital display via a PC with a CRT monitor process in the study. This display is a non-physical output and is given as a set amount of time the image is viewed on the monitor. The primary product is the PC and the CRT monitor while the consumable is electricity. Digital display via a PC with an LCD monitor is exactly the same as the Digital PC/CRT Display except that the CRT monitor is replaced with an LCD monitor.

3.2.3 Functional Unit

Functional Capability

The functional unit in an LCA study must be chosen to encapsulate the end function that is being enjoyed by the user of the product or service. The evaluation on this basis is intended to provide some measure of the environmental effectiveness of different systems in providing the same function. The system under study is a group of products and services that provide the coupled services of image capture and image output. While the individual processes, image capture, processing and output are different, they are all connected by a common end goal of providing the user with an image.

The Life Cycle Assessment models of each of these different stages were done independently with the functional unit of each stage chosen to facilitate an overarching functional unit of the capture, processing and output required to produce one 4”x6” color image. This functional unit was selected in order to set up a baseline that could be modified in the future. Of note, are the fundamental differences between traditional film processes and digital processes; the traditional processes and thus the data sources and models are tied to a per image scheme while the digital processes (image processing and output specifically) generally have some sort of time estimate as to how long a particular process takes per image.

The table below contains information regarding the different products and services that make up the imaging chain. Because of the inherent differences in the processes involved, some conversions are necessary to associate impacts from the various products and services with a single image.

Component	Base Unit	Conversion	
Film Camera	Each	4800	images / camera
Film	m^2	571.43	images / m^2
Battery	Each	80	images / battery

Component	Base Unit	Conversion	
Digital Camera	Each	4500	images / camera
Battery	Each	100	images / battery

Retail Processing			
Component	**Base Unit**	**Conversion**	
Retail Equipment	Each	5,940,000	images / minilab
Retail Chemistry	Per liter	240	Images / liter

Retail Printing			
Component	**Base Unit**	**Conversion**	
Retail Equipment	Each		
Retail Chemistry	Per liter	195	Images / liter

Wholesale Processing			
Component	**Base Unit**	**Conversion**	
Wholesale Equipment	Each	2.376*10^9	Images / whsl lab
Wholesale Chemistry	Per liter	216	Images / liter

Wholesale Printing			
Component	**Base Unit**	**Conversion**	
Wholesale Equipment	Each		
Wholesale Chemistry	Per liter	357	Images/liter

Digital Processing			
Component	**Base Unit**	**Conversion**	
Computer	Each	33120	images / comp

Inkjet Printing			
Component	**Base Unit**	**Conversion**	
Inkjet Printer	Each	3000	images / printer

Table 4: Functional units

3.2.4 Consumer Imaging Scenarios

The following are brief descriptions of the ten scenarios that were developed. The ten scenarios include two fully traditional, film based scenarios, four fully digital scenarios and four hybrid scenarios. There are two scenarios that begin with traditional film capture, and eight that begin with digital capture. The significant difference in number of options after digital and film capture is due to the greater flexibility of digital information. The flexibility is, at least, a functional advantage of beginning with a digital capture.

The first scenario, Film Capture to Retail Print (FC/R), involves a traditional film capture process combined with a local retail processing and printing operation typical of drug store operations in the US where processing and printing are done on site. The second scenario, Film Capture to Wholesale Print (FC/W), is the same capture option, but processing and printing is done in a large volume facility that is typically fed from many retailers.

The next four scenarios that are presented are all hybrid systems that begin with digital capture and end with a traditional output. The processing component of these involves transferring the digital images from a camera to the printing operation via a personal computer (PC) with either a CRT or LCD monitor These scenarios include Digital Capture to CRT Retail Print (DC/CR), Digital Capture to LCD Retail Print (DC/LR), Digital Capture to CRT Wholesale Print (DC/CW), Digital Capture to LCD Wholesale Print (DC/LW).

The final four scenarios are all purely digital options; once again both monitor options (CRT & LCD) are included. There are two inkjet print options, Digital Capture to CRT Inkjet Print (DC/CI), Digital Capture to LCD Inkjet Print (DC/LI) and two display options, Digital Capture to Display CRT (DC/CD), Digital Capture to Display LCD (DC/LD).

3.2.5 Assessment Boundaries

There are several types of boundaries involved in LCA. These boundaries can be imposed on the study by outside influences or chosen by the studies practitioners. When incorporating LCA datasets that have been developed by others, one may have to incorporate the boundaries of the outside data set into the study at hand. Lack of available data may force one to incorporate boundaries that are not necessarily the most advantageous for ones study. Boundaries can be broken down into natural boundaries and artificial boundaries. Artificial boundaries include Life Cycle Phase boundaries which are chosen by the practitioners or imposed on them by the inclusion of external studies. Natural boundaries are those related to the natural world, such as geographical or temporal boundaries.

3.2.6 Life Cycle Phases

Each Life Cycle Assessment must define the phases that are used to define the boundaries of the study. These phases help to identify where in the life cycle the impacts occur and the impacts of each phase in relation to the others. In this study there are four impact categories: upstream, distribution, use and end-of-life. These four where chosen to isolate distinct phases in the systems life, to limit the phases to a manageable set and to ensure compatibility among different processes.

The first phase, Upstream, is an amalgamation of mining, material processing and manufacturing. These phases share some common traits, such as heavy industrialization, automation and utilization of mass production philosophy. While further partitioning of this phase could be useful, this aggregation of phases was necessitated by some of the external data sources that were required for completion of the study.

The second phase, distribution, involves packaging and shipping the product from the manufacturing center to the use site. Each of the different imaging stage process models had their distribution phases built from these models. The LCA models used for the distribution phases included three different modes of transportation. These modes were shipment by sea, air freight and ground transport via truck. The product's shipping weight and the distances for each of the utilized modes of transport were used to complete the distribution phases. Generally only the major leg of distribution are considered and any further repack or local shipping after this are neglected.

Primary consumer interaction is captured in the use phase. In order to ensure comparability, the use phase was developed with the philosophy of functional capability. The imaging stages for each scenario include the impacts assessed for a single flash image capture, processing and output. The lifetimes of the different products and the quantities of consumables used per functional unit are determined for each module. The consumer use model for these functionally linked modules was developed for each module individually while keeping the functional units compatible. No other functions were included in the assessment. Additionally, consumer habits were not considered, such as the capture of multiple digital images and deleting some on the camera before printing the remaining images. Further work, incorporating actual consumer usage patterns could lead to further insight regarding the use phase of this process.

The last phase, end-of-life, involves the impacts associated with the transportation and disposal at the end of the useful life. The composition of this phase is similar to the distribution phase in that it includes a general transportation model that is applied to all of the different products. The products mass and a general distance to landfill are used to complete the end of life phase. Recycling the materials was not included but would be a useful exploration.

3.2.7 Spatial & Temporal Boundaries

The spatial and temporal boundaries of this particular study were heavily influenced by data availability. Since there was such a wide variety of products and processes involved in the study, spatial and temporal boundaries were stretched at times to allow the inclusion of products or processes that would otherwise have not been able to be included. The spatial boundaries are related to both the life cycle phases and the individual LCA modules. Since the US market is being studied, both the use phase and the end-of-life phase geographical boundaries are limited to the US. Production facilities for the different products involved in the study are located in many different places in the world. The geographical boundaries for the various LCA modules and life cycle phases are shown in the table below.

LCA Module	**Geographic Boundaries Per Life Cycle Phase**			
	Upstream	**Distribution**	**Use**	**End-of-Life**
Film Camera	China	Worldwide	US	US
Film	US	US	US	US
Battery	Worldwide	Worldwide	US	US
Digital Camera	China	Worldwide	US	US
Retail Equipment	US		US	US
Retail Chems	US	US	US	US
Electricity Use	Worldwide	Worldwide	US	US
Photo Paper	US	US	US	US
Wholesale Equipment	US	US	US	US
Wholesale Chems	US	US	US	US
PC	China	Worldwide	US	US
LCD	China	Worldwide	US	US
CRT	China	Worldwide	US	US
Inkjet printer	China	Worldwide	US	US
Inkjet Cartridge	China	Worldwide	US	US
Inkjet Paper	China	Worldwide	US	US

Table 5: Geographical boundaries for LCA models and phases

The data developed for and incorporated into this study comes from a variety of sources and was developed at a variety of times. While ties to current processes are extremely important for data relevance, lack of data led to data needs dictating the temporal boundaries, rather than the chosen temporal boundaries guiding data gathering operations. The internally developed product or process LCA's were developed with data that was accurate at the time of the study. When data was required from outside sources or incorporated from previous studies, there was not much opportunity to update the external data. With the wide range of sources for data, the range of time that this study spans is roughly ten years.

3.2.8 General Exclusions

The infrastructure, facilities as well as service, repairs and maintenance of equipment are not included explicitly in this study. These items do have appreciable impacts when assessed individually. However an attempt to incorporate them into the context of this study and the functional unit of a single image capture to output, has many difficulties. The incorporation of these items would likely have more of an impact on the impacts associated with the more expensive, larger systems that have more longevity. This is due to a more likely repair scenario instead of replacement when dealing with larger and more expensive systems. Problems with allocation and relatively extraordinarily long life spans as well as difficulties in gathering the actual data leads to a situation where it's inclusion is potentially of little relevance to the study.

3.3 Inventory Analysis

3.3.1 LCA Modules

With the broad range of different processes under investigation the approach to performing this imaging LCA had to leverage as much existing data as possible. Data was drawn from existing internal and external sources where possible. If data was not readily available, further internal studies were completed. The processes under investigation were divided into ten different imaging stages. These imaging stages in turn were divided into sixteen different LCA modules which are shown in the table below.

LCA Modules	**Data Source**
Film Camera	Teardown
Film	Internal
Battery	External
Digital Camera	Teardown
Retail Equipment	Internal
Retail Chemistry	Internal
Electricity Use	External
Photo Paper	Internal
Wholesale Equipment	Internal
Wholesale Chemistry	Internal
Personal Computer	External
LCD Monitor	External
CRT Monitor	External
Inkjet printer	Teardown
Inkjet Cartridge	Teardown
Inkjet Paper	Internal

Table 6: LCA modules

<u>Data Sources</u>

The external studies were publicly available data either in the form of government studies or LCA databases. Life cycle inventories for these different studies were adapted for use within the larger imaging scheme. Data for many of the upstream processes was found in commercially available software / database packages.[22] [23] The data sets within these software packages vary in quality and documentation and there may be multiple entries for the same process or material. The best sets where chosen in terms of data quality, completeness and consistency and these, where possible, were used consistently across the imaging process models.

Product teardowns consisted of a break down of the particular system and an assessment of the material types and weights. These break downs were connected with database entries to provide the upstream phase of its lifecycle. The product packaging, total mass and country of origin and mode of transportation provided the basis for the distribution phase. Again, in the distribution phase, LCA databases where critical in tying measures and information to impacts. Product literature as well as further measurement was used to complete the use phase. The end of life phase was developed using the known product material make up and masses along with an estimate for typical disposal transportation.

Internally developed studies allow the greatest control over data but at a higher development cost. Additionally outside sources, in terms of suppliers, are likely to still be necessary. The ease at which these studies can be done depends on the level of information available and its format. Frequently, data is not collected per “product” (for example utility information is usually tracked per building). The allocation necessary to break out impacts for a specific product further complicates the inventory process.

3.3.3 Assumptions

Lifetime assumptions can have a dramatic effect on the end results of any LCA. Since the focus with LCA is that of a function provided to the users, the “amount” of this function that the system is able to provide over its lifetime is critical. This, of course, depends on the definition of the functional unit in the study. For the sake of simplicity, lifetimes for the main systems in this study where given approximate values. These values were in terms of either images or time. The systems that were tied directly to imaging had lifetimes that reflected this, in terms of number of images. The computer and monitor systems were given lifetimes in terms of time, to cope with the fact that they were used for different processes in the different imaging stages. This format also provides some flexibility in parameter variation for these processes. The table below shows some of the selected assumptions for the systems as well as some of the consumables these systems require for operation. These assumptions were developed from a variety of sources including design specifications, physical testing or service reporting of performance.

Lifetime or Usage Assumption	Parameters	Units
Film Camera	4800	images/camera
Film	1	image/frame of film
Battery (Film Camera)	80	images/battery
Digital Camera	4500	images/camera
Battery (Digital Camera)	75	images/battery
Retail Film Processing Equipment	5940000	images/equipment
Wholesale Film Processing Equipment	2376000000	images/equipment
Digital Processing / Uploading Time	2	minutes / image
CRT Monitor Lifetime	375000	minutes / CRT Monitor
PC Lifetime	331200	mintutes / PC
LCD Monitor Lifetime	1350000	minutes / LCD Monitor
Photopaper	64.58	images / m^2
Retail Printing Equipment	5940000	images/equipment
Wholesale Printing Equipment	2376000000	images/equipment
Inkjet printer	3000	images / printer
Inkjet Cartridge	200	images / Cartridge
Inkjet Paper	216.58	images / m^2 (8x11)
Printing Time	1.79	minutes
Display Time	10	minutes

Table 7: Lifetime and usage assumptions

3.4 Impact Assessment

3.4.1 Impact Categories

According to ISO standard 14042, impact indicators are a "quantifiable representation of an impact category" while an impact category is a "class representing environmental issues of concern to which LCI results may be assigned."[24] While ISO standardized the process of performing an LCA, the organization did not specify what impact categories or indicators should be used. For guidance in which issues to focus on several factors were considered. Kodak's HSE goals, summarized below, were used to identify several general issues that are important to the company. These tie into the third thesis question regarding strategic environmental issues.

Kodak's HSE Goals[25]

- Reduce emissions of 28 priority chemicals by 15%
- Reduce emissions of methylene chloride by 35%
- Reduce greenhouse gas emissions (primarily carbon dioxide) by 10%
- Reduce the use of energy by 10%
- Reduce the use of water by 20 %
- Reduce waste from manufacturing by 20%
- Strengthen product stewardship programs by reducing the use of lead solder and chromium (VI) corrosion protection treatment in 95 percent of new products; and improving our planning for the full life cycle of all our products.
- Improve employee health and safety performance by reducing the "Worker Safety Incident Rate" by 50 percent.

From these eight Health, Safety and Environmental goals, four general issues were identified. These issues were greenhouse gasses, energy use, water use and waste generation. These issues were selected for further investigation due to their generality. Because this study involves different types of products, services and technologies, the impact assessment categories need to be general in order to not abnormally skew the results in favor or against of one particular technology or product.

Generally there are three "types" of impact category: Environmental Quality, Natural Resource Use and Human Health Impacts. The four issues that were focused on in this study fall into the environmental quality and natural resource use categories. These impact indicators are shown below with the category of impact and units involved. While there are a myriad of other issues that are important, due to the scope and goals for the study and availability of data, this limited set was chosen. This is by no means a complete set of indicators; however, they provided a useful baseline for this study. In the future more indicators could be incorporated.

With the broad range of products and services under scrutiny, as well as the variety of data sources, the impact categories were chosen carefully. There are a variety of environmental impacts; however, four categories were selected to assess the environmental impact of the different processes. These categories and the units of measure were selected and are shown in the table below. After the initial results compilation, the values were normalized.

Impact Category	Unit
Greenhouse Emission	kg CO2 Eq.
Energy Use	MJ
Water Use	m3
Waste Generation	kg

Table 8: Impact categories

These categories represent a subset of a complete list of all environmental impacts. A complete list is sometimes complicated to generate because a consensus of all environmental impacts is difficult to come to. Additionally, there are some limitations in the categories that have been chosen. For example, waste is not all equally damaging to the environment. The particular properties of each material disposed of can have different affects on the environment. Cataloging each of these and developing a more complicated set of waste impact categories would be of use, but is not done here in order to simplify the impact assessment and maintain the connection to the environmental goals.

3.4.2 Normalization

The results were computed in terms of the four impact categories. Greenhouse Emission was calculated in terms of kilograms of carbon dioxide equivalent while the Energy Use category was computed in terms of mega Joules. Water Use and Waste

Generation were in terms of cubic meters and kilograms, respectively. The results presented in this thesis are normalized in order to disguise some results that may contain proprietary information. The results were normalized across the scenario results and then separately normalized across the processes results. This separate normalization allows a comparison across scenarios and then between the different imaging stages.

3.4.3 Sensitivity Analysis

Many assumptions must be made for the different life cycle models. Some of these assumptions are of dubious quality, but in the interest in completing the study, they must be made. The influence of such assumptions on the results is explored through sensitivity analysis. These analyses use the initial results as a baseline and compare them to the change in the results when the assumptions are altered to determine how much of an influence the assumption has.

The parameters selected for variation in the sensitivity analysis are based on the lifetime and usage parameters in each of the imaging process LCA models. The table below contains these parameters. These parameters are to be varied to 50% of their value and 200% of their value. The impact results will then be compared to the baseline results in order to determine to what extent these parameters influence the scenario and process results.

LCA Module Variation Parameters
Film Camera Lifetime
Film Usage
Battery (Film Camera) Usage
Digital Camera Lifetime
Battery (Digital Camera) Usage
Retail Film Processing Equipment Lifetime
Wholesale Film Processing Equipment Lifetime
Digital Processing / Uploading Usage
CRT Monitor Lifetime
PC Lifetime
LCD Monitor Lifetime
Photopaper Usage
Retail Printing Equipment Lifetime
Wholesale Printing Equipment Lifetime
Inkjet Printer Lifetime
Inkjet Cartridge Usage
Inkjet Paper Usage
Printing Time
Display Time

Table 9: Parameters for variation

Following the calculation of the results with the parameter variations, a qualitative assessment of the foundation for each of these parameters compared with their relative influence will be completed. Each parameter will be assessed based on the likelihood of that parameters variation and the influence the parameter has on the results. The parameters that have a high likelihood of variation as well as high influence on the results would be the most volatile parameters and thus may justify further investigation.

3.5 Improvement Assessment

Once the baseline results were calculated, the high impact areas of the life cycle and imaging stages can be identified. The areas where this high impact is shown are those areas that are focused on first for improvement assessment. The drivers for the impacts can also be extracted from the results for a general concept of what variables, aspects and areas of the processes are responsible for key impacts. While these high value areas and drivers may represent the bulk of the environmental impact, any potential for improvement throughout the lifecycle and in any of the imaging processes will be investigated.

3.6 LCA Process Model Example, Digital Camera

This section details the process of developing the LCA models for the consumer imaging scenarios. As an example, the digital capture process is presented. The first step in developing these LCA models is to identify the process itself and the systems that are involved. The process itself is defined, according to the ISO standard, in the goal and scope phase of LCA by the functional unit and boundaries of the study. The functional unit of one color four by six inch image captured, process and output is broken down into the underlying functions of capture, processing and output. These functions are isolated because of the specificity of the functions and the different equipment and consumables that they require. The process diagram below shows the process for image capture and the digital camera and battery systems that are required for digital image capture.

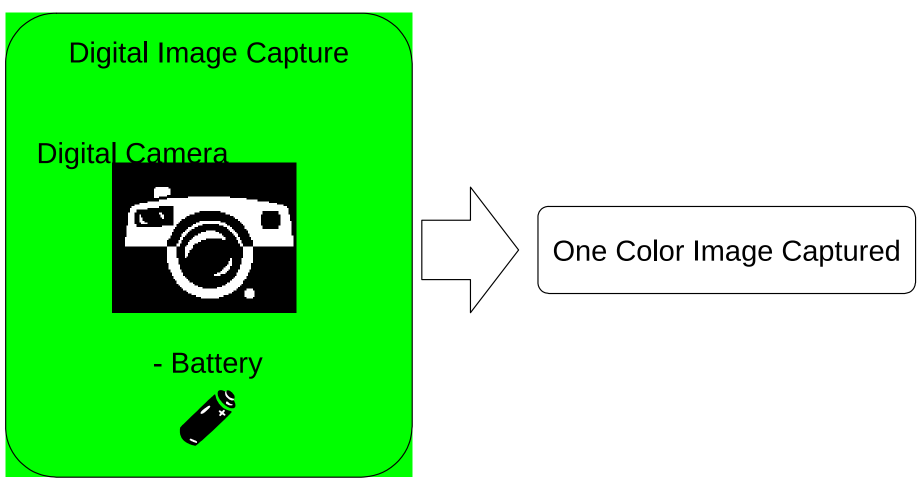

Figure 9: Digital image capture process diagram

Once the process and systems involved are identified, each of the systems must be diagramed in order to more fully understand them and their life cycles. In the early stage of the study, a wider selection of life cycle phases was included. These phases were material extraction, material processing, product manufacture, distribution, use and end of life. After incorporating externally developed data into the study, the material extraction, material processing and product manufacture had to be condensed into a single phase called upstream to maintain comparability across each of the data sets. The life cycle for the digital camera and with its components broken down is show below with the early selection of life cycle phases. For reference, some items that are not directly included in the model, such as a usage model and consumables, are shown.

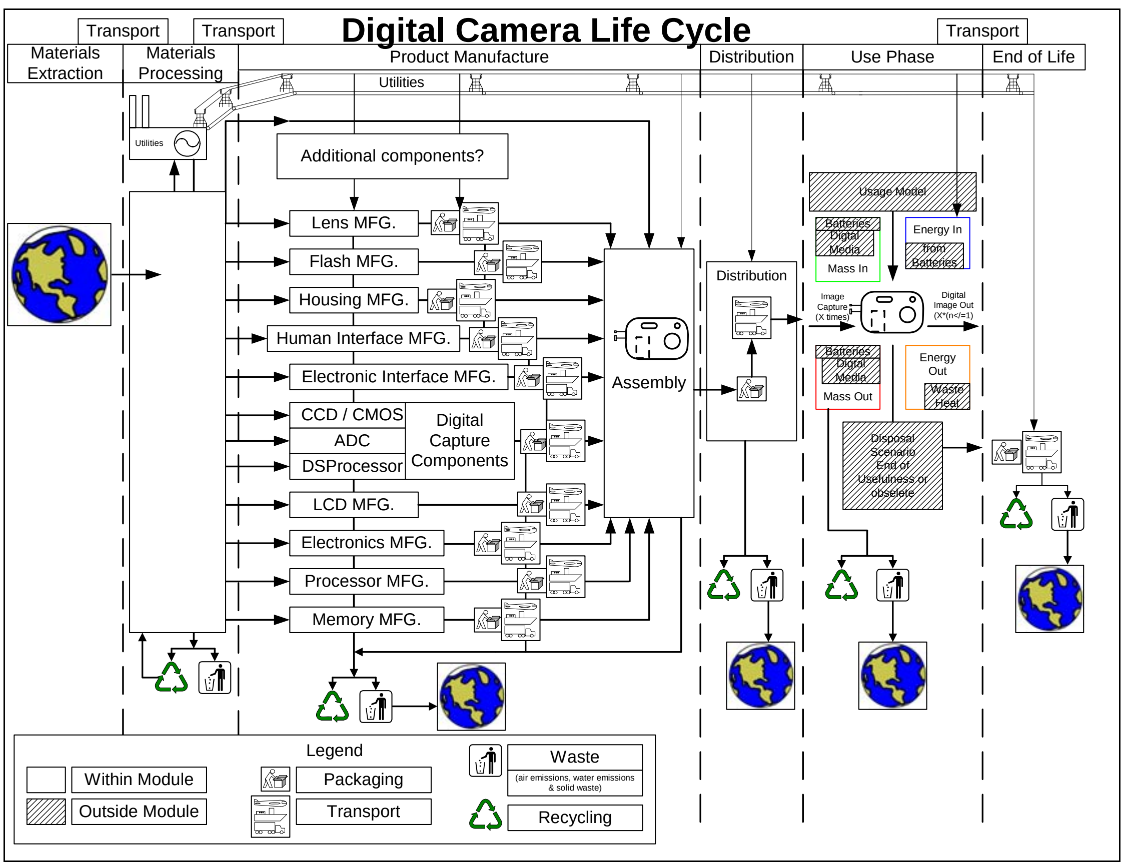

Figure 10: Digital camera life cycle diagram

After diagramming the digital camera, the other major component used in the digital imaging capture process, the battery, was explored. Several technologies exist for batteries, including alkaline, lithium ion, nickel cadmium and nickel-metal hydride. These technologies differ primarily in the electrode and electrolyte selection. Once again, the early wider selection of life cycle phases is included in the diagram, shown below. Also shown are the external items such as usage models and disposal scenarios are indicated on the diagram.

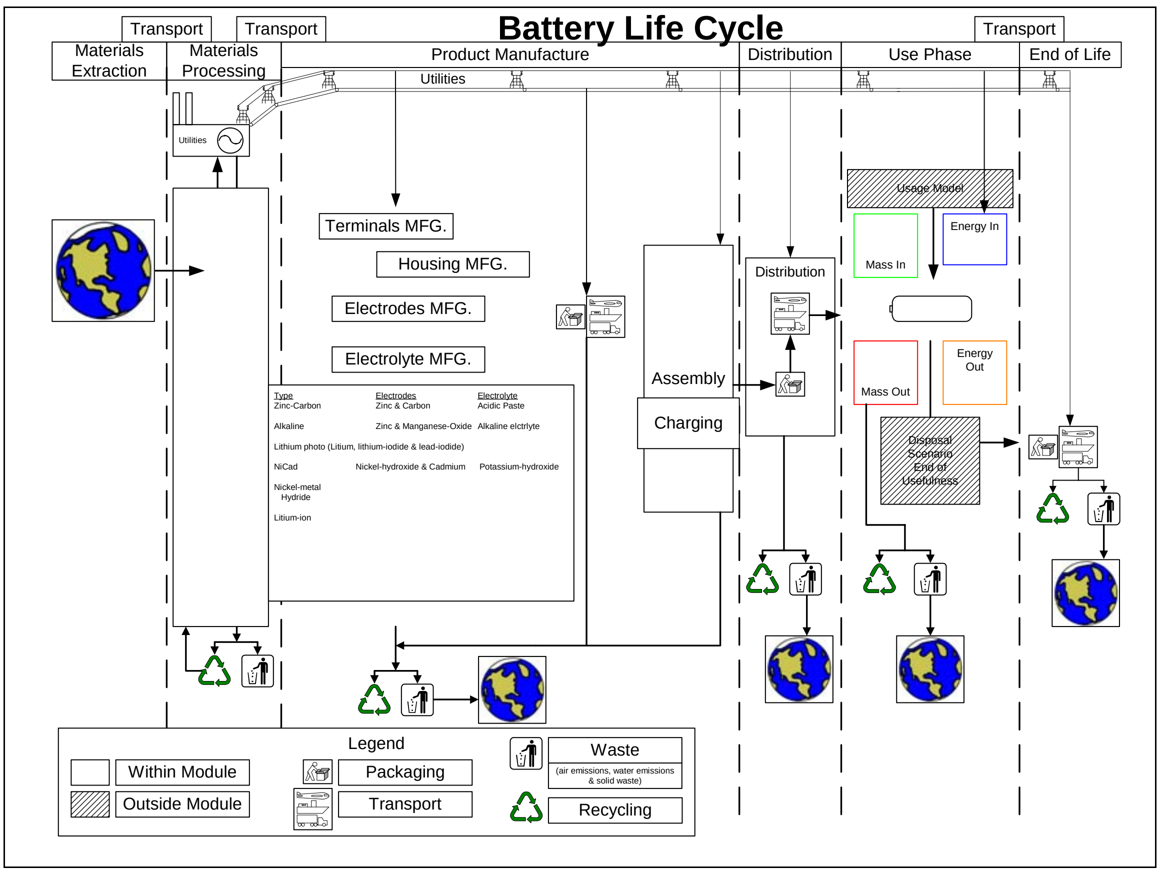

Figure 11: Battery life cycle diagram

With the life cycle diagrams completed for the digital camera and battery, the search for life cycle inventory data begins. Before beginning an exhausting internal inventory of inventory data, external sources were sought. There are several external sources for this type of information, including commercial database software, government studies, academic studies and private studies that have been release to the public. For the digital camera, there were no reports or data found from any of these sources. Lacking these reports a mid-range digital camera was selected for the study and a teardown was completed with it. This teardown comprised of dismantling the digital camera and identifying materials that went into the digital cameras manufacturing. The teardown data, which contained a weight and type of material, were then linked with material data sources found in the SimaPro software databases. These material data sources provided life cycle inventory for the material itself and the manufacturing processes involved in producing the digital camera components. For example, a specific type of plastic such as polycarbonate would have a dataset in SimaPro that contained the life cycle inventory for producing a certain mass of the plastic. This mass entry would be combined with a dataset for the injection molding process to develop the life cycle inventory data for the finished part. For the battery model, an alkaline AA battery was selected; the digital camera that was selected uses a pair of these size batteries. This was selected for availability of the data, which was contained in the SimaPro datasets, for its widespread availability and consumer acceptance and due to a relatively simple use phase.

Once the life cycle inventory data was completed for the digital camera and battery, the final step in developing the digital image capture process model was determining the use phase parameters. Since the functional unit for this process was the capture of a single image, these parameters were how many images the digital camera can capture in its lifetime and how many images it can capture on a set of batteries. These parameters were determined from the design specifications. The camera itself was designed for around 4500 images and it could capture around 200 images per set of two batteries. With these parameters, the use phase was completed and a final output in terms of the selected environmental impact categories could be calculated for each image captured. The lifetime parameter allows for the cameras impacts to be divided among each of the images that it captures in its lifetime while the battery usage parameter allocates the portion of the impacts from the batteries to a single image. Once each image process module was completed for each of the imaging stages, capture, processing and output, the consumer imaging scenarios could be compiled.

3.7 Goal Evaluation

After the process is brought to completion, comparison of the results and the original goals is done to identify what have been completed and what gaps may exists between results and original goals. Additionally, the study could bring to the surface areas for investigation outside the original goals. These will each need to be handled on a case by case basis. Further investigation on subjects outside the original goals may very well require additional commitment of resources beyond the original mandate. The value of these subjects must be weighed against the cost for development.

CHAPTER 4 - RESULTS

The following section details the results obtained for ten different consumer-imaging and output scenarios. These are shown first in a graph for each impact category and then in a table. The results for each of the twelve different process models, by life cycle phase, are also shown. The full tables of normalized results are contained in the appendices. Appendix A contains the normalized scenario results and Appendix B contains the normalized process results.

The results were computed in terms of the four impact categories. Greenhouse Emission was calculated in terms of kilograms of carbon dioxide equivalent while the Energy Use category was computed in terms of mega Joules. Water Use and Waste Generation were in terms of cubic meters and kilograms, respectively. The results presented in this thesis are normalized in order to disguise some results that may contain proprietary information. The results were normalized across the scenario results and then separately normalized across the processes results. This separate normalization allows a comparison across scenarios and then between the different imaging stages. Following the normalization, sensitivity analysis was performed by varying the key assumptions and assessing the response of the results. Key assumptions include lifetime and usage rate assumptions, especially for digital processes. These assumptions were based on design specifications, physical testing or known process details where appropriate.

4.1 Results, Scenario Comparisons

<u>Greenhouse Emissions</u>

Greenhouse emissions results for the imaging scenarios are shown in Figure 4.1, below. While the first scenario, Film Capture to Retail, is clearly the highest result in Greenhouse Emission, it is interesting to note how many of the scenarios are close to the midpoint here. Also of note is that the electricity generation details were known for the traditional side upstream processes while upstream electricity generation details for many of the other processes were not known. This resulted in a very specific, fossil fuel energy generation model for the FC/R module while a general model of the US generation sources was used for other processes. The inclusion of nuclear, hydro and other electricity generation from the average US grid mix lowers the Greenhouse Emission impact per kWhr. This is part of the reason why the FC/R result for Greenhouse Emission is the highest while in the Energy Use category it is surpassed by the DC/CD scenario while most of the other scenarios maintain their relative order.

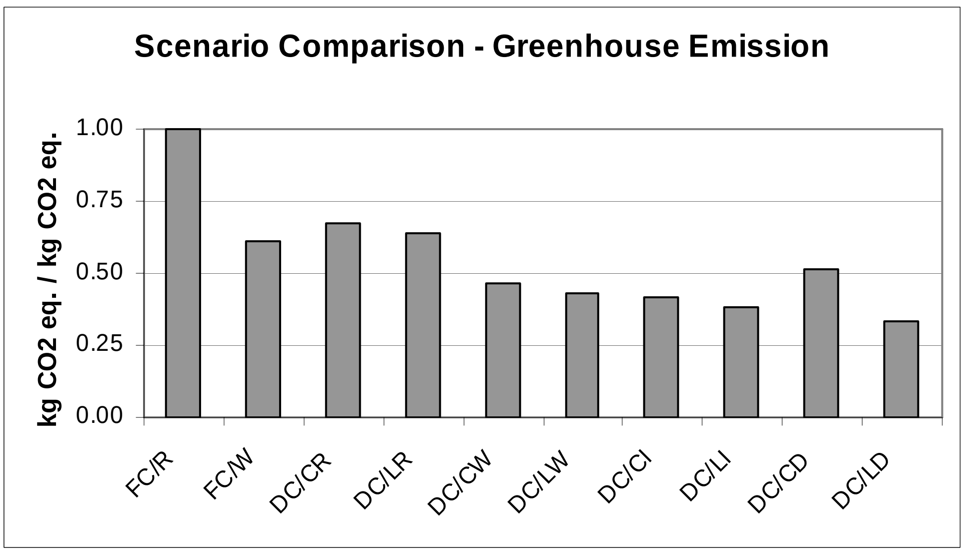

Figure 12: Scenario comparison – greenhouse emission

Energy Use

As may be expected, the results for Energy Use, in Figure 4.2, and Greenhouse Emission, in Figure 4.1, were closely linked as the majority of electricity generation involved combustion of fossil fuels. The Water Use category also proved to be tied closely to energy use for the digital scenarios. This was due to tracking of water used in hydropower operations in the modes for electricity generation. The electricity models used in the digital side differed from those used in the traditional film production. The film production electricity generation was modeled from Kodak’s own electricity generation while the digital side used a module developed based on the average US electricity generation. The inclusion of hydropower related water makes the water use category somewhat contentious.

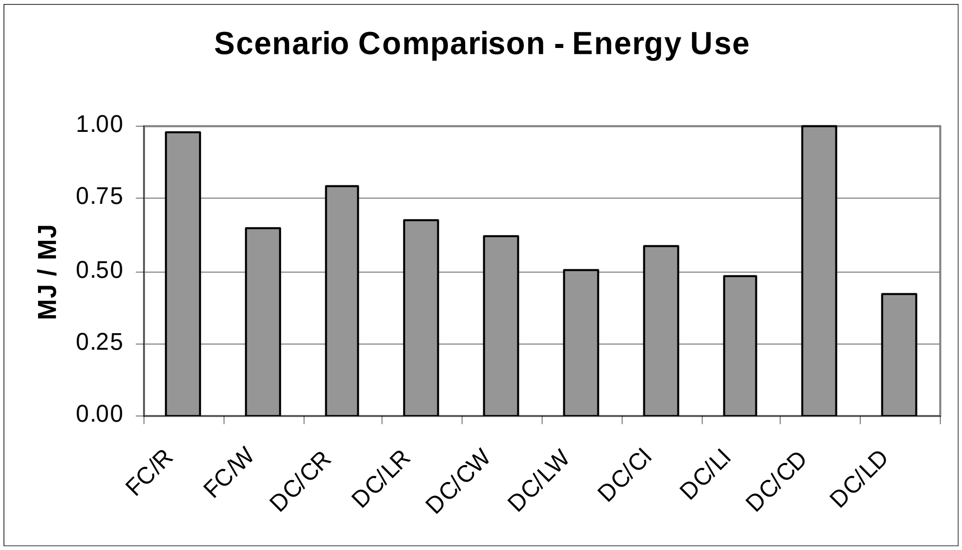

Figure 13: Scenario comparison – energy use

Water Use

Figure 4.3, below, shows the results in the water use impact category for the ten imaging scenarios. The high value for water use for DC/CD is linked to the output stage and the CRT monitor, primarily in two of its phases. The majority (about two thirds) of it is linked to the upstream phase while around a quarter of it is associated with the use phase. The upstream impacts are magnified because of the CRT's shorter lifespan, in comparison to an LCD monitor. This use phase water impact is of a questionable nature, because the grid mix electricity module includes turbine water from hydroelectric generation.

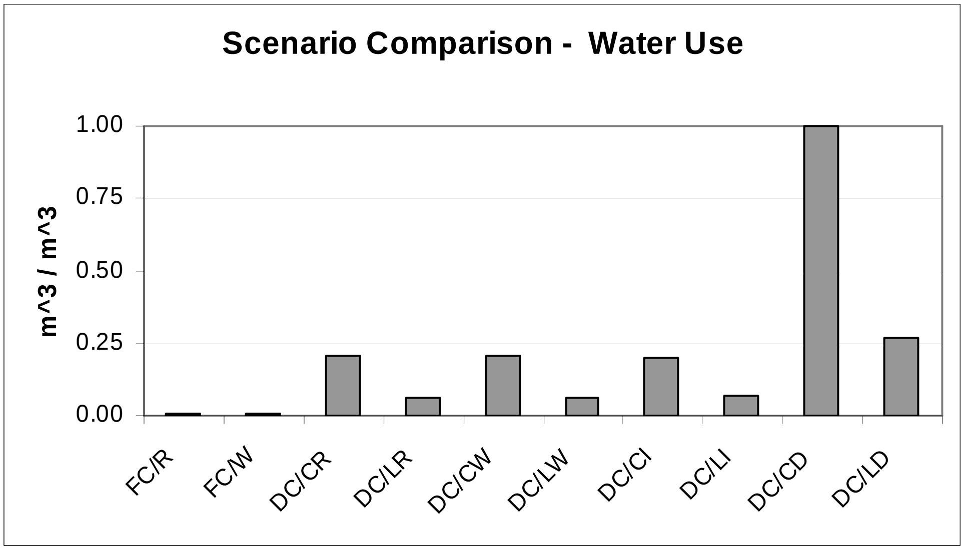

Figure 14: Scenario comparison – water use

<u>Waste Generation</u>

The final impact category results, waste generation, are shown in Figure 4.4, below. The waste generation results are dominated by the inkjet output options. The sources of these impacts are primarily the upstream life cycle phases and are related to electronics manufacturing with some additional impact during the end of life. The lifetime assumption for the printer is less than the lifetimes assumed for other electronic devices. This helps explain the high impact scores in these particular scenarios.

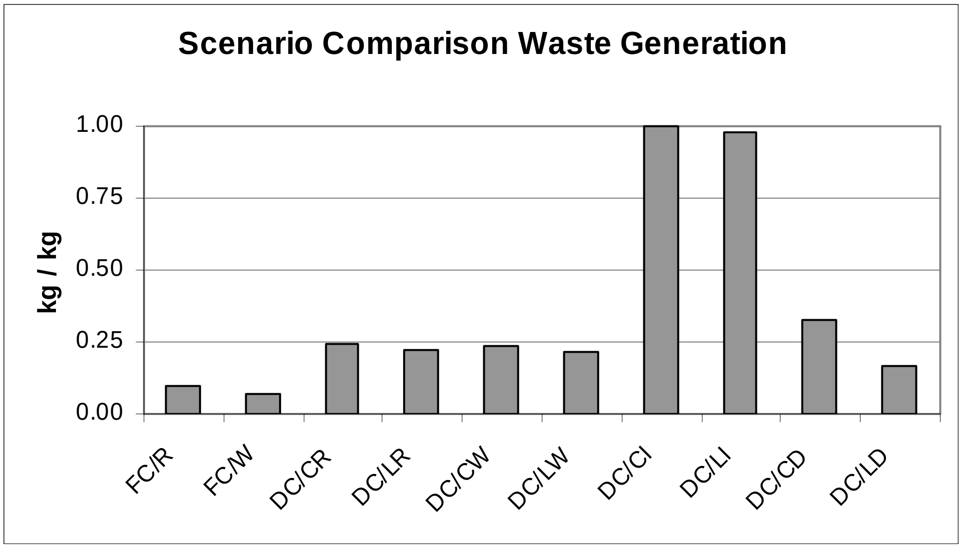

Figure 15: Scenario comparison – waste generation

Scenario Overview

The table below contains the normalized scenario results totaled for each of the different impact categories. The units for these results after normalization are: Greenhouse Emission – kg CO2 eq. / kg CO2 eq, Water Use – m^3 / m^3, Waste Generation – kg / kg and Energy Use – MJ / MJ. The bold-faced values represent highs for a particular category, while the italicized values indicate the low values. A comparison of the different scenarios, looking at all of the impact categories results at one time indicates that no one scenario performs best or worst in all four categories. Two scenarios have the lowest impacts in two out of the four impact categories. One of these scenarios uses a wholesale printing operation while the other uses LCD Display as its output. A comparison of this wholesale output with their retail output counterparts indicates more of a savings in the Greenhouse Emission and energy use categories than in water use and waste generation. It can be suggested that these results indicate an advantage of economies of scale. It is important to note that these advantages would decrease if the wholesale equipment lifespan, in terms of images, was reduced. One example of this reduction could be if the output operation is not utilized at full capacity.

	Greenhouse Emissions	Water Use	Waste Generation	Energy Use
FC/R	**1.00**	0.0075	0.0952	0.980
FC/W	0.613	***0.0064***	***0.0685***	0.651
DC/CR	0.677	0.205	0.241	0.795
DC/LR	0.641	0.0595	0.219	0.679
DC/CW	0.467	0.205	0.239	0.619
DC/LW	0.431	0.0594	0.217	0.503
DC/CI	0.414	0.199	**1.00**	0.585
DC/LI	0.382	0.0682	0.980	0.481
DC/CD	0.515	**1.00**	0.325	**1.00**
DC/LD	***0.334***	0.271	0.165	***0.420***

Table 10: Results overview

The high results in FC/R for Greenhouse Emission are related to use, and they are tied to energy use, film, and chemicals. The high results in DC/CD are related to electricity use and upstream manufacturing. High waste generation results are made worse by the relatively short lifespan assumption for inkjet printers.

4.2 Results, Process Comparison

While some assumptions can be made about the process results by comparing the scenario results, a closer look at the process results is warranted. The charts below have a comparison of the various process life cycle phases per impact category. Upstream, distribution, use and end of life impacts for each process are shown in these figures for each of the impact categories. These results have been normalized separately from the scenario results presented above.

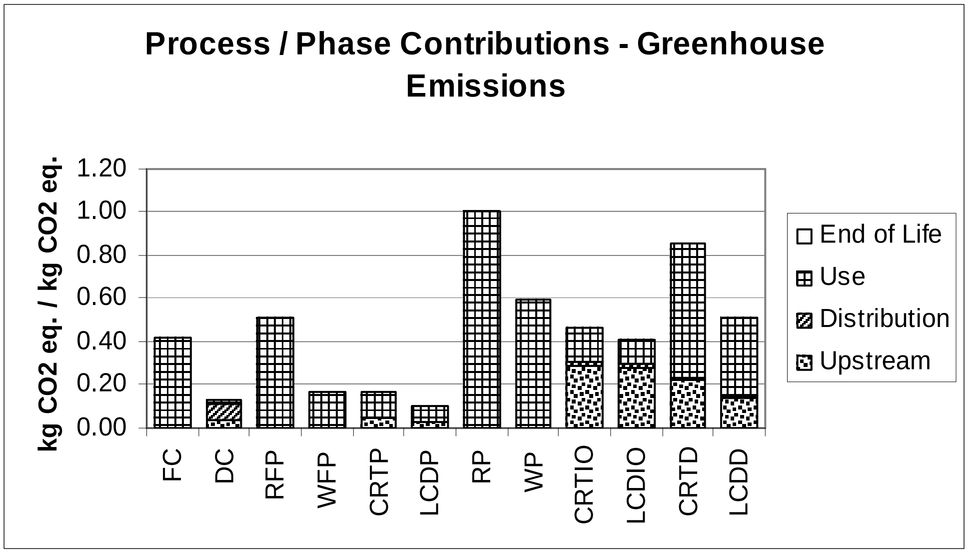

Figure 16: Process results – greenhouse emission

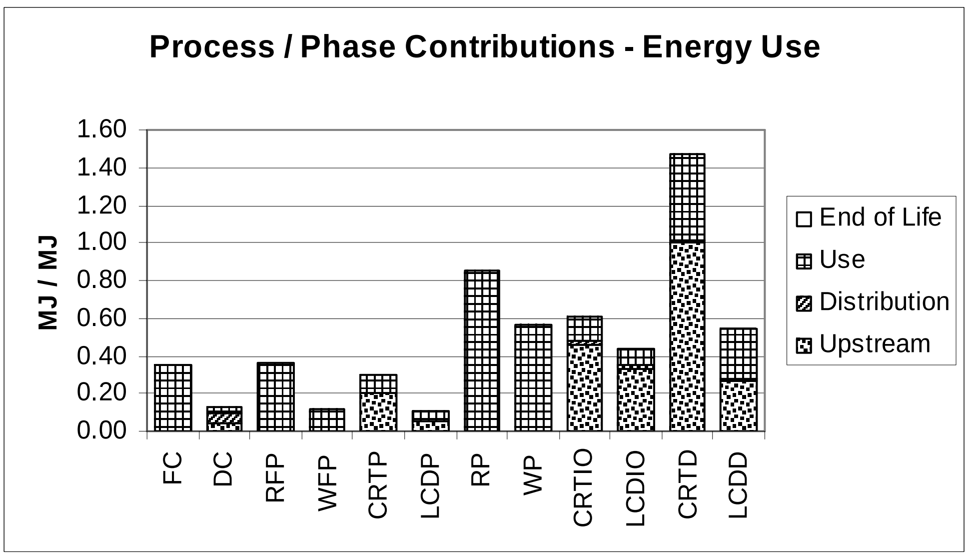

Figure 17: Process results – energy use

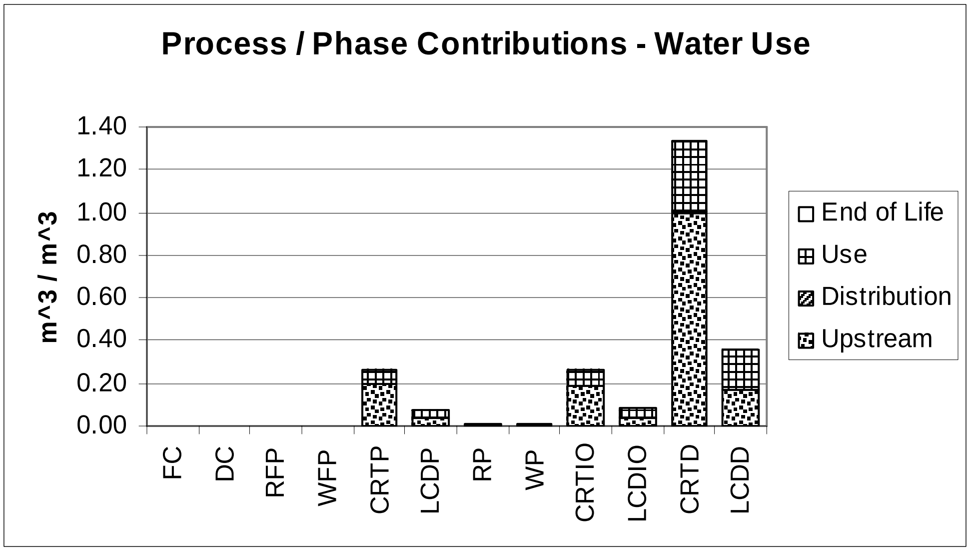

Figure 18: Process results – water use

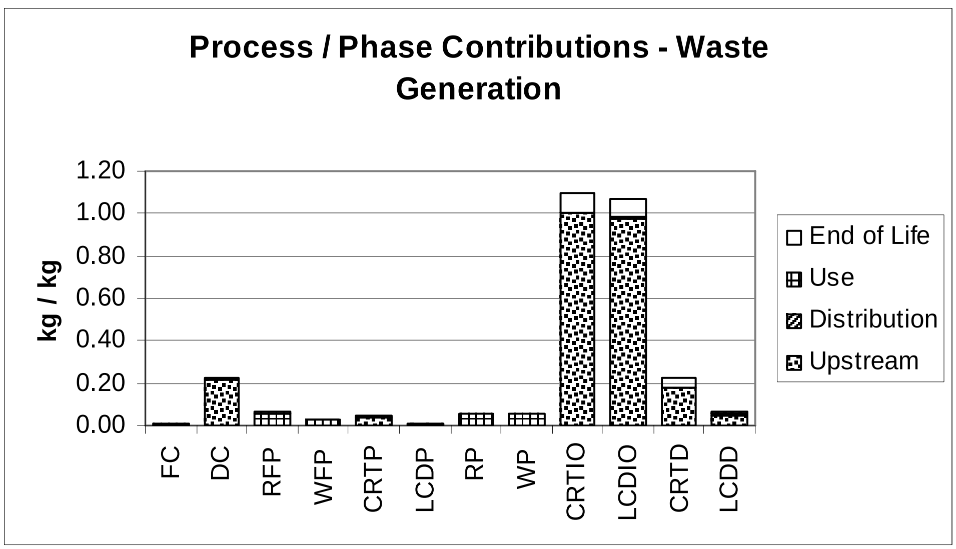

Figure 19: Process results – waste generation

While these phases are not selected to in any way be "equal" to each other, it is interesting to note the large disparity. The end-of-life phase has almost unnoticeable impact in most categories and makes up only a fraction of the impact in waste generation. Similarly, the distribution phase is a fraction of the impacts for all of the impact categories and processes. The largest impact for the distribution phase occurs in the Greenhouse Emission and energy use categories, and they are associated with transportation energies related to the shipment of products from manufacturing sites (sometimes overseas) to the market.

This being said, the use and upstream phases dominate the process impacts. There tends to be more impact from the upstream categories for digital output processes while the traditional processes impacts focus on the use phase. Part of this difference is due to the differences in the processes themselves. The traditional output systems are service systems. This means that the equipment is generally sized larger (to handle many individuals printing needs) but has a much longer lifetime than typical consumer products. The long product lifetimes of the traditional processing and printing equipment leads to a low impact, per image, from this equipment's manufacture. A comparison of the impacts for traditional retail and wholesale processing and printing indicate that there certainly are benefits as a result of the economies of scale in this product/service system. In contrast, the shorter lifetimes and heavy use of electronics in the digital systems are tied to the larger portion of impact from their upstream phases.

4.3 Sensitivity Analysis

4.3.1 Sensitivity Analysis Introduction

Motivation

In the development of the LCA modules, many assumptions or simplifications have been made. These simplifications were undertaken for a variety of reasons. Some values, such as lifespan, may vary in a population of systems or devices. Other values may not be completely clear as to an exact number for the value and so a estimate must be used. In order to proceed with the study a simplification of the value was required as determining to great detail the actual system value was not practical. After such an assumption has been made, it is important to understand what affects the assumptions make to the results of the study. The understanding of these assumptions is critical to the proper interpretation of the results. With this in mind, a sensitivity analysis was performed for several of the assumptions.

Setup

Sensitivity analysis was performed for the major assumptions at the process level. These assumptions were generally of two types. The first type of assumption was a lifetime assumption related to a piece of equipment that is utilized in a process. The second type is that of a usage rate of a consumable that is utilized in a process. The LCA modules had results with units that were, in many cases, different from each other and determined in terms relating to the particular module itself. The lifetime and usage rate assumptions then had units in terms relating the module to the main functional unit, for example, images per lifetime of a camera.

There were nineteen different process assumptions that were parameterized for the sensitivity analysis. One parameter was varied while the remaining ones were held constant. Two variations were made, one with the value twice as much as the original, baseline value and the other with the value half as much as the baseline value. The impacts were then recorded and compared in order to assess what sort of influence each of the parameters had over the scenario results. The number of processes and scenarios that were influenced by the parameters is also noted with the results. Table 4.2, below, has the parameters, their baseline values and the number of processes and scenarios that are influenced by the parameter. Table 4.3, below has the baseline parameter and the two variations made on these parameters.

LCA Module Variation	Baseline Parameters	Units	Number of Processes Affected	Number of Scenarios Affected
Film Camera Life	4800	images / camera	1	2
Film Usage	1	image / frame of film	1	2
Battery (Film Camera) Usage	80	images / battery	1	2
Digital Camera Life	4500	images / camera	1	8
Battery (Digital Camera) Usage	75	images / battery	1	8
Retail Film Processing Equipment Life	5940000	images / equipment	1	1
Wholesale Film Processing Equipment Life	2376000000	images / equipment	1	1
Digital Processing / Uploading Usage	2	minutes / image	2	4
CRT Monitor Life	375000	minutes / CRT monitor	3	4
PC Life	331200	mintutes / PC	6	8
LCD Monitor Life	1350000	minutes / LCD monitor	3	4
Photopaper Usage	64.58	images / m^2	2	6
Retail Printing Equipment Life	5940000	images / equipment	1	3
Wholesale Printing Equipment	2376000000	images / equipment	1	3
Inkjet printer	3000	images / printer	2	2
Inkjet Cartridge	200	images / Cartridge	2	2
Inkjet Paper	33.16	images / m^2 (8x11)	2	2
Printing Time	2	minutes	2	2
Display Time	10	minutes	2	2

Table 11: Sensitivity analysis setup

LCA Module Variation	Baseline Parameters	50% Variation	200% Variation	Units
Film Camera Life	4800	2400	9600	images / camera
Film Usage	1	0.5	2	image / frame of film
Battery (Film Camera) Usage	80	40	160	images / battery
Digital Camera Life	4500	2250	9000	images / camera
Battery (Digital Camera) Usage	75	37.5	150	images / battery
Retail Film Processing Equipment Life	5940000	2970000	11880000	images / equipment
Wholesale Film Processing Equipment Life	2376000000	1188000000	4752000000	images / equipment
Digital Processing / Uploading Usage	2	1	4	minutes / image
CRT Monitor Life	375000	187500	750000	minutes / CRT monitor
PC Life	331200	165600	662400	mintutes / PC
LCD Monitor Life	1350000	675000	2700000	minutes / LCD monitor
Photopaper Usage	64.58	32.29	129.16	images / m^2
Retail Printing Equipment Life	5940000	2970000	11880000	images / equipment
Wholesale Printing Equipment	2376000000	1188000000	4752000000	images / equipment
Inkjet printer	3000	1500	6000	images / printer
Inkjet Cartridge	200	100	400	images / Cartridge
Inkjet Paper	33.16	16.58	66.32	images / m^2 (8x11)
Printing Time	2	1	4	minutes
Display Time	10	5	20	minutes

Table 12: Sensitivity analysis parameter variations

The results are presented in several different ways. The first set of results is intended to determine the parameter that has the greatest influence on a single impact score. To this end, the absolute values of each of the individual scenario impacts were compared for each parameter that was varied. The results were then tabularized in order of absolute value to display the relative impact each parameter had in terms of largest change from the baseline.

The second set of results is intended to determine which parameter had the overall greatest influence in the scenario results. This was done by computing the average absolute value of the change in the scenario impacts for each of the parameters. The results were once again tabularized in order of absolute value to display the relative average impact change from baseline for each parameter. Finally, the scenario results for each of the parameters are presented and discussed within the context of the initial impact results and how the sensitivity analysis impacts the interpretation of the impact results. Appendix C contains the full tables of scenario results from the sensitivity analysis.

4.3.2 Sensitivity Analysis Results

<u>Highest Absolute Difference in Scenario Results</u>

This is a list of the greatest (in absolute value) percent differences among scenario impacts for each of the parameters that were varied. These values are the highest actual individual impact differences from each of the parameter shifts.

Max Absolute Difference	Max % Scenario Change	Processes Affected
Display Time	99.95%	2 (D)
Digital Processing / Uploading Time	98.85%	2 (D)
Digital Camera Lifetime	96.90%	1 (D)
Printing Time	95.85%	2 (D)
Inkjet Printer Lifetime	77.94%	2 (D)
CRT Monitor Lifetime	66.18%	3 (D)
Photopaper Use	63.84%	2 (T)
PC Lifetime	37.94%	6 (D)
Film Use	33.34%	1 (T)
Inkjet Paper Use	27.15%	2 (D)
LCD Monitor Lifetime	13.70%	3 (D)
Battery (Digital Camera)	8.25%	1 (D)
Battery (Film Camera)	6.99%	1 (T)
Retail Printing Equipment	3.97%	1 (T)
Inkjet Cartridge	2.51%	2 (D)
Film Camera Lifetime	2.17%	1 (T)
Retail Film Processing Equipment	1.56%	1 (T)
Wholesale Printing Equipment	0.15%	1 (T)
Wholesale Film Processing Equipment	0.10%	1 (T)

Table 13: Maximum absolute difference

Of particular interest here is the distribution of the digital and traditional parameters in the max scenario ranking. The top six maximum scenario percent changes are found among digital parameters and eight of the top ten are digital processes. While there are three more digital parameters than traditional parameters, there is still a marked trend of traditional processes having less extreme maximum percent changes in the scenario impacts. Potential reasons for this difference include differences in process aspects between digital and traditional systems as well as differences in product oriented systems and the longer lifespan of service systems.

Highest Average Percent Change in Scenario Results

This is a list of the average (across all impacts and scenarios) change in scenario results from the parameter variation. The "maximum" refers to the fact the results included in this list were the highest change from either the 50% variation or the 200% variation.

Max Average Percent Difference	Max Avg % Change in Scenario Results	Processes Affected
Digital Camera Lifetime	17.13%	1 (D)
Display Time	14.68%	2 (D)
Digital Processing / Uploading Time	14.49%	2 (D)
Photopaper Use	13.80%	2 (T)
CRT Monitor Lifetime	10.72%	3 (D)
Inkjet Printer	7.70%	2 (D)
PC Lifetime	7.61%	6 (D)
Printing Time	6.82%	2 (D)
Film	3.70%	1 (T)
Inkjet Paper	2.77%	2 (D)
LCD Monitor Lifetime	1.91%	3 (D)
Battery (Digital Camera)	1.71%	1 (D)
Battery (Film Camera)	0.50%	1 (T)
Retail Printing Equipment	0.24%	1 (D)
Inkjet Cartridge	0.22%	2 (D)
Film Camera Lifetime	0.16%	1 (T)
Retail Film Processing Equipment	0.058%	1 (T)
Wholesale Printing Equipment	0.009%	1 (T)
Wholesale Film Processing Equipment	0.004%	1 (T)

Table 14: Maximum average percent change

Like the maximum scenario change table, the digital processes in this one tend to dominate the higher ranks. However traditional parameters also tend to affect fewer processes. From both of these tables the traditional processes seem to have a lower influence in percent change of scenario impact and influence fewer scenarios. Digital processes however seem to have a higher variation as well as process influence due to their potential for flexibility.

Process Ranks

The table below contains the imaging processes and the parameters that affect them in the order of relative impact. Traditional processes seem to be more influenced by consumable variation in the use phase than in variation of the equipment lifetimes. In contrast there doesn’t seem to be a consensus among the digital processes. Some, like digital capture, are most influenced by the equipment life, while others, like processing or display are most influenced by the amount of time required for the process rather than the lifetime of the equipment. However, even when the digital equipment lifetimes aren’t the highest in percent change, they are always significant, sometimes coming in a close second in influence.

Process	Avg % Change in Scenario Results					
	1	2	3	4	5	6
Film Capture	Film Usage	Battery Usage	Film Camera Life			
	3.70%	0.50%	0.16%			
Digital Capture	Digital Camera Life	Battery Usage				
	17.13%	1.71%				
Retail Film Processing	RFP Equipment Life					
	0.058%					
Wholesale Film Processing	WFP Equipment Life					
	0.007%					
Digital PC/CRT Processing	Processing / Uploading Time	CRT Monitor Life	PC Life			
	14.49%	10.72%	7.61%			
Digital PC/LCD Processing	Processing / Uploading Time	PC Life	LCD Monitor Life			
	14.49%	7.61%	1.91%			
Retail Printing	Photopaper	RP Equipment				
	11.41%	0.24%				
Wholesale Printing	Photopaper	WP Equipment				
	11.41%	0.007%				
Digital PC/CRT Inkjet Printing	CRT Monitor Life	Inkjet Printer	PC Life	Printing Time	Inkjet Paper	Inkjet Cartridge
	10.72%	7.70%	7.61%	6.82%	2.77%	0.22%
Digital PC/LCD Inkjet Printing	Inkjet Printer	PC Lifetime	Printing Time	Inkjet Paper	LCD Monitor Life	Inkjet Cartridge
	7.70%	7.61%	6.82%	2.77%	1.91%	0.22%
Digital PC/CRT Display	Display Time	CRT Monitor Life	PC Life			
	14.68%	10.72%	7.61%			
Digital PC/LCD Display	Display Time	PC Life	LCD Monitor Life			
	14.68%	7.61%	1.91%			

Table 15: Parameter process ranks

Film Camera Life

The film camera life variation modifies how many images are assumed to be captured during the camera's useful life. The baseline assumption was developed from design criteria of 200 rolls of twenty-four exposure for a film camera. The base value for this variable is 4800 images per camera and the sensitivity analysis variation runs from 2400 to 9600 images per camera. Since the film camera is only involved in two of the ten scenarios, the absolute value sum totals and averages of the change across the entire scenario results are relatively small. With the relatively small impact in the film capture process related to the film camera itself, it is not particularly surprising that a variation of the camera's lifetime would not have a dramatic influence over the scenario results. This small change in scenario results with such a wide variation in the parameter helps to establish that this particular parameter is not of great importance in the end result and that the assumption based on design specifications is adequate.

	50% of Base				**200% of Base**			
Scenario Results	**GHE**	**H2O Use**	**WG**	**E Use**	**GHE**	**H2O Use**	**WG**	**E Use**
Film Camera	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.178%	0.653%	1.560%	0.297%	-0.089%	-0.327%	-0.780%	-0.148%
FC/W	0.290%	0.756%	2.167%	0.447%	-0.145%	-0.378%	-1.084%	-0.224%
DC/CR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Absolute Value Sums	0.468%	1.41%	3.73%	0.744%	0.234%	0.705%	1.863%	0.372%
Absolute Value Sum Total	6.35E-02	**Average:**	**1.59E-03**		3.17E-02	**Average:**	**7.93E-04**	

Table 16: Film camera life variation results

Film Usage

Although the average of all of the absolute changes in scenario results is relatively low, this is mainly due to this consumables inclusion of in only two of the ten scenarios. Within the two scenarios involving film processing, however, the influence of this parameter are marked. With significant changes in three of the four impact categories, this parameter has some significant impact on the scenario results it is involved in. As may be expected, the impacts from this variation are most pronounced in the impact categories that have larger values in the process results. The parameter itself starts as a baseline value one image per frame of film and varies from a half an image per frame to two images per frame. The film capture process is unlikely to vary this much and so the baseline is a much more reasonable number. The variation was explored more to gain some idea of how variation of the parameter impacted the results compared to other parameters than because the chosen variation seemed likely. Issues that are more likely to occur are things like multiple captures of the same image. A detailed study of image capture consumer behavior would be required to determine how common such multiple captures are though. Even though variation of this parameter led to some significant scenario impact changes, the structure of the study, focusing on a single image capture provides some justification for the selection of the baseline value.

	50% of Base				**200% of Base**			
Scenario Results	**GHE**	**H2O Use**	**WG**	**E Use**	**GHE**	**H2O Use**	**WG**	**E Use**
Flim	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	20.4%	19.4%	0.3%	20.5%	-10.2%	-9.7%	-0.2%	-10.3%
FC/W	33.3%	22.5%	0.5%	30.9%	-16.7%	-11.2%	-0.2%	-15.5%
DC/CR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Absolute Value Sums	53.8%	41.9%	0.819%	51.5%	26.9%	21.0%	0.409%	25.7%
Absolute Value Sum Total	1.48E+00	**Average:**	**3.70E-02**		7.40E-01	**Average:**	**1.85E-02**	

Table 17: Film usage variation results

Battery (Film Camera) Usage

The battery usage parameter for film camera capture models the rate at which batteries are used by the film camera by its systems such as film advance, rewind and flash, among others. The film camera uses two AA batteries and the projected life of these batteries is 160 captures with flash. The base value, determined from design specifications, was set at eighty images per battery. Variation of the parameter then led to a high of one hundred and sixty images per battery and a low of forty images per battery. The variation of this particular parameter does not point to it having an extremely significant influence over the scenarios it is involved in nor over the complete scenario set of scenario results. Combined with the source of the baseline parameter, direct from design engineers, the significance of this particular parameter on the end results is fairly low.

	50% of Base				200% of Base			
Scenario Results	**GHE**	**H2O Use**	**WG**	**E Use**	**GHE**	**H2O Use**	**WG**	**E Use**
Battery (Film Camera)	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	1.11%	0.320%	5.03%	1.76%	-0.557%	-0.160%	-2.52%	-0.882%
FC/W	1.82%	0.370%	6.99%	2.66%	-0.909%	-0.185%	-3.50%	-1.33%
DC/CR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Absolute Value Sums	2.93%	0.690%	12.0%	4.42%	1.47%	0.345%	6.01%	2.21%
Absolute Value Sum Total	2.01E-01	**Average:**	**5.02E-03**		1.00E-01	**Average:**	**2.51E-03**	

Table 18: Battery (film camera) usage variation results

Digital Camera Life

Like the film camera life parameter, the digital camera life parameter defines how many images a digital camera captures during its useful lifetime. The assumption for the digital camera lifetime was based on an expected lifetime from design specifications. The baseline value for the parameter is 4500 images per digital camera. The low and high variations go from 2250 to 9000 images per camera. This range provides a significant variation in scenario results involving digital capture. In fact, the variation of the digital camera lifetime has the one of the most significant influence on the total scenarios over all other parameters. Since it is the process that is most used in the scenarios, this is not completely unexpected. Although the baseline value was provided via the product design, the wide range of variation, with a basis in real functional variation as well, in scenario results upon sensitivity analysis and the potential for replacing cameras for newer models before true end of life does suggest that future work should include a study of digital camera life in the use phase.

	50% of Base				200% of Base			
Scenario Results	**GHE**	**H2O Use**	**WG**	**E Use**	**GHE**	**H2O Use**	**WG**	**E Use**
Digital Camera	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
FC/W	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CR	8.46%	0.250%	66.5%	7.87%	-4.23%	-0.125%	-33.3%	-3.93%
DC/CW	12.3%	0.250%	67.0%	10.1%	-6.13%	-0.125%	-33.5%	-5.05%
DC/LR	8.94%	0.864%	73.2%	9.21%	-4.47%	-0.43%	-36.6%	-4.60%
DC/LW	27.5%	0.940%	82.1%	28.0%	-13.7%	-0.47%	-41.1%	-14.0%
DC/CI	13.8%	0.258%	16.0%	10.7%	-6.91%	-0.13%	-8.01%	-5.34%
DC/LI	15.0%	0.753%	16.4%	13.0%	-7.50%	-0.38%	-8.18%	-6.50%
DC/CD	11.1%	0.051%	49.3%	6.25%	-5.57%	-0.03%	-24.7%	-3.12%
DC/LD	17.2%	0.190%	96.9%	14.9%	-8.58%	-0.09%	-48.5%	-7.43%
Absolute Value Sums	114%	3.56%	467%	99.9%	57.1%	1.78%	234%	50.0%
Absolute Value Sum Total	6.85E+00	**Average:**	**1.71E-01**		3.43E+00	**Average:**	**8.56E-02**	

Table 19: Digital camera life variation results

Battery (Digital Camera) Usage

Similar to the film camera battery usage, the digital camera battery usage parameter controls the rate at which the digital camera uses batteries during operations. Product comparative performance disclosures indicate a battery life of 150 images with two AA batteries. The baseline parameter is seventy-five images per battery determined from this design specification and testing for product marketing information. Variation of the parameter goes from a low of 37.5 images per battery to a high of 150 images per battery. In contrast to the film camera operation however, there is much more potential for variation in battery consumption with digital cameras because of their additional features. With variation in usage of the camera itself, using the LCD screen instead of the viewfinder, photo management features and other features, the potential for variation in consumer behavior and thus in energy use is clear. The lower relative impact of the variation of this parameter in comparison to others however indicates that even with a likelihood of variation of energy use in normal digital camera use, this parameter does not have a huge impact on the environmental impact scores.

	50% of Base				200% of Base			
Scenario Results	**GHE**	**H2O Use**	**WG**	**E Use**	**GHE**	**H2O Use**	**WG**	**E Use**
Battery (Digital Camera)	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
FC/W	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CR	1.75%	0.012%	2.12%	2.32%	-0.877%	-0.006%	-1.06%	-1.16%
DC/CW	2.54%	0.012%	2.13%	2.98%	-1.27%	-0.006%	-1.07%	-1.49%
DC/LR	1.85%	0.043%	2.33%	2.72%	-0.927%	-0.021%	-1.17%	-1.36%
DC/LW	5.70%	0.046%	2.62%	8.25%	-2.85%	-0.023%	-1.31%	-4.12%
DC/CI	2.87%	0.013%	0.51%	3.15%	-1.43%	-0.006%	-0.255%	-1.58%
DC/LI	3.11%	0.037%	0.52%	3.83%	-1.56%	-0.019%	-0.261%	-1.92%
DC/CD	2.31%	0.003%	1.57%	1.84%	-1.15%	-0.001%	-0.786%	-0.922%
DC/LD	3.56%	0.009%	3.09%	4.39%	-1.78%	-0.005%	-1.54%	-2.19%
Absolute Value Sums	23.7%	0.176%	14.9%	29.5%	11.8%	0.088%	7.45%	14.7%
Absolute Value Sum Total	6.83E-01	**Average:**	**1.71E-02**		3.41E-01	**Average:**	**8.53E-03**	

Table 20: Battery (digital camera) usage variation results

Retail Film Processing Equipment Life

The equipment life parameter for retail film processing controls how many images the equipment can process in its lifetime. The image count expected in the equipment's life is determined from a calculation based on 15 years, 50 rolls per day, 330 operating days per year which yields 247,500 rolls per life times 24 exposures per roll yields 5.94 million. The baseline assumption is 5,940,000 images per set of retail film processing equipment. This leads to a high and low variation from 11,880,000 to 2,970,000 images per set of retail film processing equipment. This particular system is included in only one scenario, and, as may be expected has one of the lowest impact on scenario results. The low influence this parameter has on the results and the fact that it only influences one scenario can be used to make the case that this particular parameter is not of great significance.

	50% of Base				200% of Base			
Scenario Results	**GHE**	**H2O Use**	**WG**	**E Use**	**GHE**	**H2O Use**	**WG**	**E Use**
Retail Film Processing Equipment	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.145%	0.439%	1.56%	0.165%	-0.073%	-0.220%	-0.780%	-0.083%
FC/W	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Absolute Value Sums	0.145%	0.439%	1.56%	0.165%	0.073%	0.220%	0.780%	0.083%
Absolute Value Sum Total	2.31E-02	**Average:**	**5.77E-04**		1.15E-02	**Average:**	**2.89E-04**	

Table 21: Retail film processing equipment life variation results

Wholesale Film Processing Equipment Life

Like the other equipment life variables, this particular one defines how many images the wholesale film processing equipment can process in its lifetime. The equipment lifetime in images is estimated based on 30 year lifetime 10,000 orders per day, 330 operating days for 99,000,000 rolls per expected life. With 24 exposures per roll, this comes to a baseline value of 2,376,000,000 images in the equipments life. The high and low variations then are 4,752,000,000 and 1,188,000,000 images per set of equipments. While this process model does not include a detailed assessment of the service and maintenance impacts, the influence when the lifetime is varied is extremely small and only affects one scenario. It thus does not have a great influence over the scenario results.

	50% of Base				200% of Base			
Scenario Results	**GHE**	**H2O Use**	**WG**	**E Use**	**GHE**	**H2O Use**	**WG**	**E Use**
Wholesale Film Processing Equipment	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
FC/W	0.017%	0.023%	0.099%	0.016%	-0.009%	-0.012%	-0.049%	-0.008%
DC/CR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Absolute Value Sums	0.017%	0.023%	0.099%	0.016%	0.009%	0.012%	0.049%	0.008%
Absolute Value Sum Total	1.55E-03	**Average:**	**3.88E-05**		7.76E-04	**Average:**	**1.94E-05**	

Table 22: Wholesale film processing equipment life variation results

Digital Processing / Uploading Usage

The digital processing / uploading usage parameter controls the time assumed to upload and process the digital image. This includes the use of a computer with either a CRT or LCD monitor. The baseline assumption is 2 minutes per image and the parameter variation ranges from 1 minute to 4 minutes. This particular parameter influences four of the ten scenarios and is in the top three, nearly tied for second of all parameters in influence. This heavy influence over so many scenarios justifies future investigation of consumer behavior in this area.

	50% of Base				200% of Base			
Scenario Results	**GHE**	**H2O Use**	**WG**	**E Use**	**GHE**	**H2O Use**	**WG**	**E Use**
Digital Processing / Uploading Time	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
FC/W	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CR	-6.58%	-48.7%	-6.63%	-11.6%	13.2%	97.3%	13.3%	23.1%
DC/CW	-9.53%	-48.7%	-6.67%	-14.8%	19.1%	97.4%	13.3%	29.7%
DC/LR	-4.13%	-45.4%	-2.25%	-5.00%	8.26%	90.8%	4.50%	10.0%
DC/LW	-12.7%	-49.4%	-2.52%	-15.2%	25.4%	98.9%	5.044%	30.4%
DC/CI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Absolute Value Sums	32.9%	192%	18.1%	46.6%	65.9%	384%	36.1%	93.2%
Absolute Value Sum Total	2.90E+00	**Average:**	**7.24E-02**		5.80E+00	**Average:**	**1.45E-01**	

Table 23: Digital processing / uploading time variation results

CRT Monitor Life

The CRT monitor life parameter controls how many minutes are in the life of the typical CRT monitor useful life. The baseline assumption of 375,000 minutes was derived from the US EPA and University of Tennessee report on computer displays.[26] The variation ranges from 187,500 minutes on the low end to 750,000 on the high end. As may be expected because of a higher usage of the monitor, the digital capture / CRT display is the scenario that this parameter influences the most. Ranking in the top five highest influencing parameters, the CRT monitor life value is definitely important to the results. However, the source of the assumption, a detailed multi-year study, somewhat mitigates this high variability.

	50% of Base				200% of Base			
Scenario Results	**GHE**	**H2O Use**	**WG**	**E Use**	**GHE**	**H2O Use**	**WG**	**E Use**
CRT Monitor Lifetime	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
FC/W	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CR	2.48%	64.5%	9.94%	11.9%	-1.24%	-32.2%	-4.97%	-5.97%
DC/CW	3.59%	64.5%	10.0%	15.3%	-1.80%	-32.2%	-5.01%	-7.66%
DC/LR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CI	3.63%	59.6%	2.15%	14.5%	-1.81%	-29.8%	-1.07%	-7.27%
DC/LI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CD	16.3%	66.2%	36.9%	47.4%	-8.15%	-33.1%	-18.4%	-23.7%
DC/LD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Absolute Value Sums	2.60E-01	255%	59.0%	89.2%	13.0%	127%	29.5%	44.6%
Absolute Value Sum Total	4.29E+00	**Average:**	**1.07E-01**		2.14E+00	**Average:**	**5.36E-02**	

Table 24: CRT monitor life variation results

PC Life

The lifetime parameter for the personal computer LCA model was derived from the European Unions Ecolabel report on the product group of personal computers.[27] The baseline value for this parameter is 331,200 minutes with the high and low variations at 662,400 and 165,600, respectively. This parameter rates fairly high (within the top ten) in total influence. However, when the source for the baseline value and the high number of scenarios it is included are considered, this helps to reinforce that the baseline value is an acceptable one.

	50% of Base				200% of Base			
Scenario Results	**GHE**	**H2O Use**	**WG**	**E Use**	**GHE**	**H2O Use**	**WG**	**E Use**
PC Lifetime	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
FC/W	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CR	1.07%	8.77%	3.31%	4.01%	-0.537%	-4.39%	-1.65%	-2.01%
DC/CW	1.56%	8.78%	3.33%	5.15%	-0.778%	-4.39%	-1.67%	-2.58%
DC/LR	1.13%	30.3%	3.64%	4.70%	-0.567%	-15.1%	-1.82%	-2.35%
DC/LW	3.49%	32.9%	4.08%	14.3%	-1.745%	-16.5%	-2.04%	-7.13%
DC/CI	1.57%	8.12%	0.714%	4.88%	-0.786%	-4.06%	-0.357%	-2.44%
DC/LI	1.71%	23.7%	0.728%	5.94%	-0.853%	-11.8%	-0.364%	-2.97%
DC/CD	7.07%	9.01%	12.3%	15.9%	-3.53%	-4.50%	-6.13%	-7.97%
DC/LD	10.9%	33.3%	0.00%	37.9%	-5.45%	-16.6%	0.00%	-19.0%
Absolute Value Sums	28.5%	155%	28.1%	92.9%	14.3%	77.4%	14.0%	46.4%
Absolute Value Sum Total	3.04E+00	**Average:**	**7.61E-02**		1.52E+00	**Average:**	**3.80E-02**	

Table 25: PC Life variation results

<u>LCD Monitor Life</u>

The lifetime assumption for the LCD monitor defines how many minutes of useful life can be extracted from an LCD monitor. Like the CRT monitor, information for the LCD monitor was found in the US EPA and University of Tennessee report on computer displays.[28] The baseline value is 1,350,000 minutes per monitor and varies from a high of 2,700,000 and a low of 675,000 minutes per monitor. This parameter placed in the lower half of the set of parameters in total influence and together with the source of the baseline value this indicates that the baseline value is likely an acceptable value.

	50% of Base				200% of Base			
Scenario Results	**GHE**	**H2O Use**	**WG**	**E Use**	**GHE**	**H2O Use**	**WG**	**E Use**
LCD Monitor Lifetime	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
FC/W	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LR	1.258%	12.47%	0.855%	0.444%	-0.629%	-6.24%	-0.428%	-0.222%
DC/LW	3.867%	13.57%	0.959%	1.35%	-1.93%	-6.79%	-0.480%	-0.673%
DC/CI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LI	1.89%	9.75%	0.171%	0.561%	-0.945%	-4.87%	-0.086%	-0.280%
DC/CD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LD	12.1%	13.7%	0.00%	3.58%	-6.04%	-6.85%	0.00%	-1.79%
Absolute Value Sums	19.1%	49.5%	1.99%	5.93%	9.55%	24.8%	0.993%	2.966%
Absolute Value Sum Total	7.65E-01	**Average:**	**1.91E-02**		3.83E-01	**Average:**	**9.56E-03**	

Table 26: LCD monitor life variation results

Photopaper Usage

The photopaper usage parameter determines how much photographic paper is used in the image output phase of the traditional printing processes. The baseline value of 64.58 images per square meter of photopaper is based on simple area of the four by six inch image output from the functional unit. The high value variation is then 129.17 and the low value is 32.3 images per square meter. Although this parameter ranks fairly high in influence of the scenario results, variations of these extremes seem particularly unlikely to occur. The low value is simply impossible and the high value would involve such waste that economic drivers alone would push for reduction. The variations were more to keep the parameter comparison on equal level to explore how different parameters acted in the scenarios.

	50% of Base				200% of Base			
Scenario Results	**GHE**	**H2O Use**	**WG**	**E Use**	**GHE**	**H2O Use**	**WG**	**E Use**
Photopaper	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	16.8%	55.18%	10.496%	23.3%	-8.38%	-27.6%	-5.25%	-11.6%
FC/W	27.3%	63.84%	14.587%	35.1%	-13.7%	-31.9%	-7.29%	-17.5%
DC/CR	24.7%	2.00%	4.145%	28.7%	-12.4%	-1.00%	-2.07%	-14.4%
DC/CW	35.8%	2.00%	4.175%	36.9%	-17.9%	-1.00%	-2.09%	-18.4%
DC/LR	26.1%	6.91%	4.563%	33.6%	-13.1%	-3.45%	-2.28%	-16.8%
DC/LW	38.9%	6.92%	4.599%	45.4%	-19.4%	-3.46%	-2.30%	-22.7%
DC/CI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Absolute Value Sums	170%	137%	42.6%	203%	84.8%	68.4%	21.3%	101%
Absolute Value Sum Total	5.52E+00	**Average:**	**1.38E-01**		2.76E+00	**Average:**	**6.90E-02**	

Table 27: Photopaper usage variation results

Retail Printing Equipment Life

Another equipment life parameter, this retail printing equipment life controls how many images the printing equipment in a retail outlet can produce in its lifetime. The image count expected in the equipments life is determined from a calculation based on 15 years, 50 rolls per day, and 330 operating days per year which yields 247,500 rolls per life times 24 exposures per roll yields 5.94 million. The high and low variations are 11,880,000 and 2,970,000 images per set of equipment. The influence of this parameter on the scenario results is relatively low in comparison to the other parameters examined in this sensitivity analysis.

	50% of Base				200% of Base			
Scenario Results	**GHE**	**H2O Use**	**WG**	**E Use**	**GHE**	**H2O Use**	**WG**	**E Use**
Retail Printing Equipment	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.116%	0.991%	3.970%	0.137%	-0.058%	-0.496%	-1.99%	-0.068%
FC/W	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CR	0.172%	0.036%	1.57%	0.169%	-0.086%	-0.018%	-0.784%	-0.084%
DC/CW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LR	0.182%	0.124%	1.73%	0.198%	-0.091%	-0.062%	-0.863%	-0.099%
DC/LW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Absolute Value Sums	0.470%	1.151%	7.264%	0.504%	0.235%	0.576%	3.632%	0.252%
Absolute Value Sum Total	9.39E-02	**Average:**	**2.35E-03**		4.69E-02	**Average:**	**1.17E-03**	

Table 28: Retail printing equipment life variation results

<u>Wholesale Printing Equipment</u>

Another equipment life parameter, this wholesale printing equipment life controls how many images the printing equipment in a retail outlet can produce in its lifetime. The equipment lifetime in images is estimated based on 30 year lifetime 10,000 orders per day, 330 operating days for 99,000,000 rolls per expected life. With 24 exposures per roll, this comes to a baseline value of 2,376,000,000 images in the equipments life. The high and low variations are 4,752,000,000 and 1,188,000,000 images per set of equipment. The influence of this parameter on the scenario results is relatively low in comparison to the other parameters examined in this sensitivity analysis. This is to be expected since the wholesale printing equipment parameter only influences one imaging process and three scenarios.

	50% of Base				200% of Base			
Scenario Results	**GHE**	**H2O Use**	**WG**	**E Use**	**GHE**	**H2O Use**	**WG**	**E Use**
Wholesale Printing Equipment	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
FC/W	0.013%	0.032%	0.148%	0.013%	-0.007%	-0.016%	-0.074%	-0.006%
DC/CR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CW	0.017%	0.001%	0.042%	0.013%	-0.009%	-0.001%	-0.021%	-0.007%
DC/LR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LW	0.019%	0.003%	0.047%	0.016%	-0.009%	-0.002%	-0.023%	-0.008%
DC/CI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Absolute Value Sums	0.049%	0.037%	0.237%	0.042%	0.025%	0.018%	0.118%	0.021%
Absolute Value Sum Total	3.65E-03	**Average:**	**9.12E-05**		1.82E-03	**Average:**	**4.56E-05**	

Table 29: Wholesale printing equipment life variation results

<u>Inkjet printer</u>

The inkjet printer life parameter determines the number of images the printer can produce in its useful life. The life of the inkjet printer in images was based on a lifetime estimate of close to 9000 minutes of active time per printer. An estimate of three minutes to print an image at highest quality provides a baseline value of 3000 images per printer. With this baseline value is 3000 images per printer, the high and low values are 6000 and 1500 image per printer respectively. Even though this parameter only influences one process and two scenarios it ranks relatively high in influence over the scenario results. This high influence with a low inclusion in scenarios makes the case for a further investigation of this parameter.

	50% of Base				200% of Base			
Scenario Results	**GHE**	**H2O Use**	**WG**	**E Use**	**GHE**	**H2O Use**	**WG**	**E Use**
Inkjet Printer	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
FC/W	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CI	33.5%	3.24%	76.4%	32.1%	-16.7%	-1.62%	-38.2%	-16.0%
DC/LI	36.3%	9.44%	77.9%	39.0%	-18.2%	-4.72%	-39.0%	-19.5%
DC/CD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Absolute Value Sums	69.8%	12.7%	154%	71.1%	34.9%	6.34%	77.2%	35.5%
Absolute Value Sum Total	3.08E+00	**Average:**	**7.70E-02**		1.54E+00	**Average:**	**3.85E-02**	

Table 30: Inkjet printer life variation results

Inkjet Cartridge

The inkjet cartridge parameter is a consumable usage parameter. Its base value is 200 images per cartridge; with the high and low values at 400 and 100 images per cartridge, respectively. While this parameter had fairly low influence in the two scenarios it was involved in. In fact, in comparison with the inkjet printer life, it has a near insignificant impact on the inkjet output processes.

	50% of Base				200% of Base			
Scenario Results	**GHE**	**H2O Use**	**WG**	**E Use**	**GHE**	**H2O Use**	**WG**	**E Use**
Inkjet Cartridge	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
FC/W	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LW	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
DC/CI	1.88%	0.014%	0.077%	2.07%	-0.941%	-0.007%	-0.039%	-1.03%
DC/LI	2.04%	0.040%	0.079%	2.51%	-1.02%	-0.020%	-0.039%	-1.26%
DC/CD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Absolute Value Sums	3.924%	0.053%	0.156%	4.581%	1.962%	0.027%	0.078%	2.290%
Absolute Value Sum Total	8.71E-02	**Average:**	**2.18E-03**		4.36E-02	**Average:**	**1.09E-03**	

Table 31: Inkjet cartridge usage variation results

Inkjet Paper

Similar to photopaper, the inkjet paper use parameter determines how much inkjet paper is consumed in producing inkjet photographic prints. The base value is 33.16

images per square meter of inkjet paper is derived from an assumption of two images per 8 x 11 inch inkjet paper. The high and low values for the parameter variation are then 66.32 and 16.58 images per square meter of inkjet paper. The variation of this parameter indicates that it has less impact than the traditional photopaper. With the inherent waste in producing two 4 x 6 inch images from one 8 x 11 inch piece of paper in comparison to producing images from 4 x 6 photopaper with less waste, this result is somewhat surprising. The quality of the prints should thus be investigated further to assess comparability between the two methods of image output. Overall, however, the influence of inkjet paper is fairly low when compared to other parameters.

	50% of Base				**200% of Base**			
Scenario Results	**GHE**	**H2O Use**	**WG**	**E Use**	**GHE**	**H2O Use**	**WG**	**E Use**
Inkjet Paper	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.000%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
FC/W	0.000%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CR	0.000%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CW	0.000%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LR	0.000%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LW	0.000%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CI	25.0%	0.623%	4.12%	21.6%	-12.5%	-0.311%	-2.06%	-10.8%
DC/LI	27.2%	1.82%	4.21%	26.3%	-13.6%	-0.908%	-2.10%	-13.1%
DC/CD	0.000%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LD	0.000%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Absolute Value Sums	52.2%	2.44%	8.33%	47.9%	26.1%	1.22%	4.16%	23.9%
Absolute Value Sum Total	1.11E+00	**Average:**	**2.77E-02**		5.54E-01	**Average:**	**1.39E-02**	

Table 32: Inkjet paper usage variation results

Printing Time

The printing time parameter controls how much time and in turn how much energy the inkjet printer uses to print a four by six inch image. The baseline value of 1.79 minutes per image is varied from a high of 3.58 to a low of 0.89 minutes per image. This particular parameter influences only two of the imaging processes, inkjet printing with CRT and LCD monitors. Printing time ranks well behind in influence of many of the other parameters, nearly in the bottom half of the rankings. The medium to low influence and the source of the parameter, developed from testing, somewhat mitigates the importance of this parameter.

	50% of Base				200% of Base			
Scenario Results	**GHE**	**H2O Use**	**WG**	**E Use**	**GHE**	**H2O Use**	**WG**	**E Use**
Printing Time	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
FC/W	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CI	-11.5%	-47.9%	-1.43%	-15.2%	22.9%	95.9%	2.86%	30.4%
DC/LI	-8.19%	-44.0%	-0.450%	-7.70%	16.4%	87.9%	0.900%	15.4%
DC/CD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Absolute Value Sums	19.6%	91.9%	1.88%	22.9%	39.3%	184%	3.76%	45.8%
Absolute Value Sum Total	1.36E+00	**Average:**	**3.41E-02**		2.73E+00	**Average:**	**6.82E-02**	

Table 33: Printing time variation results

Display Time

The display time is one variation that has significant grounding in reality. Where some of the parameters, such as paper use vary into the unreachable zones for the sake of a comparative assessment of parameter influence, this particular process is fairly open ended. The display time parameter controls the digital image display processes for both CRT and LCD display. The baseline parameter is ten minutes per image and varies from five and twenty minutes per image. The influence of this parameter on scenario results is the second highest and has significant implications for the completely digital imaging pathway.

	50% of Base				200% of Base			
Scenario Results	**GHE**	**H2O Use**	**WG**	**E Use**	**GHE**	**H2O Use**	**WG**	**E Use**
Display Time	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
FC/W	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CD	-43.3%	-50.0%	-24.6%	-46.0%	86.6%	99.9%	49.1%	91.9%
DC/LD	-39.6%	-49.9%	-0.004%	-40.4%	79.3%	99.8%	0.007%	80.7%
Absolute Value Sums	82.9%	99.9%	24.6%	86.3%	166%	200%	49.1%	173%
Absolute Value Sum Total	2.94E+00	**Average:**	**7.34E-02**		5.87E+00	**Average:**	**1.47E-01**	

Table 34: Display time variation results

4.3.2 Sensitivity Analysis Conclusions

<u>High Influence Parameters</u>

Some of the top parameters in both high scenario impact influence and highest average scenario impact influence are digital camera lifetime, display time and digital processing / uploading time. These three parameters are closely related to consumer decisions in the use phase. Digital camera lifetime for instance, may be dramatically shortened if a consumer decides to upgrade to another camera and dispose of the old camera before it has reached the end of its useful life. Similarly, the time used to process the digital photographs as well as display can be shortened or extended depending on consumer choices during these activities. Image sharing via the internet for example is a vastly different process than showing off photographs to visiting friends. In essence this is one of the big differences between traditional imaging and digital imaging. The flexibility and interactivity of digital equipment can lead to a large amount of variability in how the equipment is used and its impact on the environment. With this potential for variability that greatly affects the scenario results, a further study of consumer behavior in the use phase seems well justified.

Digital vs. Traditional & Product vs. Service

Of particular interest in the max scenario ranking is the distribution of the digital and traditional parameters. The digital parameters tend to end up in the higher end of both the maximum scenario impact and the average scenario impact. While there are three more digital parameters than traditional parameters, this is still a marked trend of traditional processes having less extreme maximum percent changes and lower average percent changes in the scenario impacts. If the difference was simply in the average percent change, it could be attributed to the traditional parameters being involved in fewer processes and thus fewer scenarios; but, since the trend appears in both maximum and average percent change, this difference is not likely to be simply due to the structure of the study. Potential reasons for this difference include differences in process aspects between digital and traditional systems as well as differences in product oriented systems and the longer lifespan of service systems. Digital systems, for instance, have more flexibility, as can be seen by how many different scenarios they can be involved in. This flexibility could be linked to the variability in the scenario influence.

Process Ranking of Parameters

In the ranking of parameter importance for each process, a few trends were identified. First, the traditional processes seem to be more influenced by consumable variation in the use phase than in variation of the equipment lifetimes. In contrast there doesn't seem to be a consensus among the digital processes. Some, like digital capture, are most influenced by the equipment life, while others, like processing or display are most influenced by the amount of time required for the process rather than the lifetime of the equipment. However, even when the digital equipment lifetimes aren't the highest in percent change, they are always significant, sometimes coming in a close second in influence.

Conclusion

The sensitivity analysis does not serve to individually validate or invalidate models, but serves to help understand them and how to interpret them. Insight into the process models and their behavior under parameter variation has helped to identify differences in the various processes, types of image pathways and product systems. It has also helped to identify and prioritize areas for improvement or further investigation.

4.4 Goal Evaluation

After reviewing the results, the six goals specified in the methodology section had to be assessed. The table below indicates how each of these goals was met. The scenario impact results satisfy the requirement for a quantitative profile of environmental impacts while providing a baseline for consumer imaging environmental impacts. The sensitivity analysis and process results provide some insight on the drivers of the scenario impacts themselves. Process results provide an indication of which life cycle stages have the larges impacts and thus which areas may contain the most opportunity for improvement. Finally the study structure itself uses ISO standards as a guideline and provides for openness to include further process models as they may be required due to assessment of different technologies or different imaging systems and markets.

	Goals	Met by
1.	Provide a quantitative profile of environmental impacts	Scenario Impact Results
2.	Provide a quantitative profile of the impact drivers	Sensitivity Analysis and Process Results
3.	Establish a baseline for resource consumption, energy use and environmental impact information	Scenario Impact Results
4.	Identify areas life cycle stages where improvements can be made	Process Results
5.	Maintain openness necessary to expand to additional systems and various imaging applications	Study Structure
6.	Be consistent with industry practice and ISO standards	Study Structure

Table 35: Table of goals

CHAPTER 5 - CONCLUSIONS AND CLOSURE

5.1 Relating Results to Questions

5.1.1 Question One

The Question

The first question is related to a comparison of the various scenarios of consumer imaging. Specifically, question one asks: is there an environmentally preferred method of consumer imaging, is digital better than traditional imaging? The hypothesis for this question was that the digital capture and traditional processing and output would have some environmental advantages.

Results Related to Question One

The table below contains the results as well as the sum and types for each scenario. The results presented here are normalized in order to disguise some results that may contain proprietary information. When all impacts were considered, no single imaging scenario was clearly "better" or "worse" than the others. Imaging scenarios that were advantaged in one impact category were often disadvantaged in others. This leads one to believe that a more complete picture (with more impact categories) would also not show an “absolute winner.” In the table, D refers to digital technology, H refers to hybrid digital and traditional system and T refers to a completely traditional system. Also, P refers to a product system and PSS refers to a product service system.

	Greenhouse Emissions	Water Use	Waste Generation	Energy Use	Sum	Tech Type	System Type
DC/LD	0.333	0.271	0.165	0.420	1.19	D	P
DC/LW	0.431	0.0594	0.217	0.503	1.21	H	PSS
FC/W	0.612	0.00644	0.0685	0.651	1.34	T	PSS
DC/CW	0.467	0.205	0.239	0.619	1.53	H	PSS
DC/LR	0.641	0.0595	0.219	0.679	1.60	H	PSS
DC/LI	0.382	0.0682	0.980	0.481	1.91	D	P
DC/CR	0.677	0.205	0.241	0.795	1.92	H	PSS
FC/R	**1.00**	0.00745	0.0952	0.980	2.08	D	P
DC/CI	0.414	0.199	**1.00**	0.585	2.20	T	PSS
DC/CD	0.515	**1.00**	0.325	**1.00**	2.84	D	P

Table 36: Question one scenario results summary

In both greenhouse emissions and energy use, the digital capture LCD processing wholesale output scenario was the lowest scoring scenario. For water use and waste generation, the traditional film capture to wholesale processing and output was the lowest scenario. The highest impact for water use and energy use were found in the digital capture to CRT display which is also has the highest total summary of impacts. With the lowest total impact being digital capture to LCD display this certainly points to a significant technological advantage for LCD displays over CRT displays. In fact, scenarios involving LCD computer processing score lower with only one exception. In greenhouse emissions and waste generation, film capture to retail output and digital capture to CRT processed inkjet prints produced the highest impacts, respectively. With both digital and traditional processes involved in both the lower and upper summary scores, there does not seem to be a consensus as to an environmentally preferable technology.

Process results seem to indicate that of the three types of imaging functions (capture, processing and output) output tends to contribute the most to the imaging scenarios impact results. Processing, followed by capture round out the influence over the impact scores from these processes. Wholesale output seems most advantageous from the standpoint of process impacts and scenario impacts. LCD computer processing is by far the best scoring digital processing form. Options for output after this type of processing are, lowest to highest, wholesale print, display, retail print and finally, inkjet printing. CRT computer processing tends to drag down the scenario scores below those with similar output to those scenarios with LCD processing.

The sensitivity analysis of the lifetime and consumable parameters demonstrates that while digital imaging may have impact advantages, the variation of the digital camera lifetime has the most affect of all parameters on the scenario results. In contrast the variation of wholesale equipment lifetime has the least impact on the scenario results. These results give some pause to leaning towards digital capture while reinforcing the scenario results showing the advantages of wholesale output.

Conclusions

With representatives of digital and film technology, as well as hybrid systems in both the highest and lowest of the scenario impact summary, the results do not show a clear better technology. However, a clear advantage, from these results can be seen for LCD computer displays over CRT computer displays. The method of image output seems to be more important to the results than the question of original capture technology. The flexibility in digital capture tends to lead to a larger variation in results when parameters are increased or decreased. For example, digital technologies offer more choice/flexibility, resulting in a much wider range of potential impact. Time spent “processing” on a computer, for example may significantly influence energy consumption, or viewing on a soft display, and/or image capture using the LCD vs. the viewfinder.

The best pathway of completely digital technology that leads to a physical output (digital capture, LCD inkjet output) has about 25% higher impact score than the best means of physical output via traditional film technology (film capture, wholesale output).

However, this is likely to be related to the advantages of economies of scale found in wholesale output instead of an advantage of film over digital imaging since the film capture to retail output ranks as second highest total impact sum. The economies of scale relating to wholesale output include the longer life of the equipment as well as more efficient handling of material consumables in the processing and printing stages.

The study was undertaken from a functional capability point of view and actual usage habits were not included. It is clear, however, that consumer choice during the use phase can significantly influence the environmental impact. The influence of the use phase on the scenario results shows the importance of continuing to strive for energy efficiency in design and production, as well as consumer awareness of the use phase impacts and means to mitigate them.

Sensitivity analysis of the parameters tends to indicate that some further investigation of digital camera lifetime and usage may be of benefit. While the original assumption for the digital camera life was directly from the designers, the potential for consumers to upgrade to a new camera is quite real. Additionally, consumer behavior and activities in processing images on a personal computer can also drastically alter the scenario results. Further investigation of these consumer behaviors would be of benefit to understanding the use phase of the equipment.

As far as options for performance improvement in these systems, any innovation that simplifies the imaging process (e.g., printer docks or automatic on-camera image manipulation/ correction) removes impacts from the imaging chain (computer processing and display). While efforts were made to incorporate the most up-to-date information in this study, processes and technology across the industry change rapidly. The digital side, especially, is developing so rapidly that many of the suggested areas for improvement are already in play. Improvements in energy efficiency and incorporating features on-camera to eliminate process steps have already been incorporated into new systems

5.1.2 Question Two

<u>The Question</u>

The second question was related to the types of business models involved in consumer imaging. These models include both a product system and a product service system. Some have argued that service systems have inherent environmental advantages over product systems. The question was if this product service system is a preferred strategy for sustainability?

<u>Results Related to Question Two</u>

The table below contains the scenario impact scores, in rank order from lowest to highest as well as the technology type and type of system. The results presented here are normalized in order to disguise some results that may contain proprietary information. Representatives of both product and product service systems do appear at both ends of the table. However, with only one exception, the top five best performers are all product service systems. Those systems that are product service systems that are in the lower end of performance are a lower volume system and one hindered by CRT computer processing which seems to be one of the higher impact processes. In the table, D refers to digital technology, H refers to hybrid digital and traditional system and T refers to a completely traditional system. Also, P refers to a product system and PSS refers to a product service system.

	Greenhouse Emissions	Water Use	Waste Generation	Energy Use	Sum	Tech Type	System Type
DC/LD	0.333	0.271	0.165	0.420	1.19	D	P
DC/LW	0.431	0.0594	0.217	0.503	1.21	H	PSS
FC/W	0.612	0.00644	0.0685	0.651	1.34	T	PSS
DC/CW	0.467	0.205	0.239	0.619	1.53	H	PSS
DC/LR	0.641	0.0595	0.219	0.679	1.60	H	PSS
DC/LI	0.382	0.0682	0.980	0.481	1.91	D	P
DC/CR	0.677	0.205	0.241	0.795	1.92	H	PSS
FC/R	**1.00**	0.00745	0.0952	0.980	2.08	D	P
DC/CI	0.414	0.199	**1.00**	0.585	2.20	T	PSS
DC/CD	0.515	**1.00**	0.325	**1.00**	2.84	D	P

Table 37: Question two scenario results summary

The benefits of economies of scale are shown in the comparison of retail vs. wholesale processing and printing. A continuation of these shared resources and moving to a more service oriented digital output scheme would seem to be advantageous. The upstream environmental impacts for these service oriented systems tend to be mitigated by the long lifetimes of the equipment. This is similar to the economic advantages of large scale, long lived, high volume systems; the increased upfront costs for a larger system can be distributed over its long lifespan. This is advantageous both economically and environmentally as long as the benefits of the longer life outweigh the upfront costs.

The two phases that most influenced the results, across the board, were the upstream and use phase. There tends to be more impact from the upstream categories for digital output processes while the traditional processes impacts focus on the use phase. Part of this trend is related to the differences in product and service systems. The traditional processes upstream phases include the impacts from the equipment manufacturing. These impacts are then distributed over the equipments lifetime which is quite large, thus reducing the upstream impact. The use phase impacts from these processes are tied to their consumables which are handles in a bulk fashion due to the service system. Product systems tend to have much shorter lives, thus their upstream impacts are higher in these results than that of the service oriented systems.

Conclusions

The results for this question do seem to indicate that there are some advantages of a product service system over a product system. However, these advantages are somewhat tempered by the level of resource sharing involved. For example, the film output to retail output ranked in second to the highest in terms of sum of impacts while film capture to wholesale output ranked third lowest in terms of the sum of its impacts. Additionally, the technology applied in the hybrid systems indicates that different technologies applied to a scenario can have a marked impact on the ranking of the scenario. These interactions indicate that while product service systems tend to have some advantages, the introduction of new technologies to these systems can provide further, noticeable benefit as well. It takes a combination of both factors, technology and business model, to reach into the top of the results.

5.1.3 Question Three

The Question

The final question involves a company's strategic environmental performance. Evaluating issues behind these often high level goals requires information regarding many different environmental issues as well as a broad perspective of a company's activities. So, how does a company evaluate strategic environmental performance issues with new and established business activities? The hypothesis for this question is that LCA is a good approach to evaluate strategic environmental performance issues.

Results Related to Question Three

When evaluating strategic environmental performance issues, businesses face a daunting challenge that requires a broad perspective and a multidisciplinary approach while maintaining the ability to relate useful results to specific business activities. The results for the first two questions help to demonstrate the usefulness of LCA as a tool to evaluate both technology and business models. Leveraging multiple disciplines, LCA and the multiple impact scores and life cycle perspective provided the sort of broad consideration that a strategic assessment tool should. The evaluation for a comparison of technologies, presents interesting insights for digital and film imaging while the sensitivity analysis examines the influence of certain critical assumptions in the process models.

Strategic environmental issues that a company is concerned with can often be distilled from the company's corporate environmental goals. In this case, Kodak's corporate goals were used as a starting point for development of the impact indicator categories. These goals were distilled to find general environmental issues that were important to the company. It was important to select general issues rather than those that may be technology specific so as to not provide either type of system under evaluation an inherent advantage in the assessment. Next a set of impact categories were developed based on these issues and external sources. These impact categories are then used to calculate the impact category scores which allow the decision makers to see the relative comparison of the different scenarios and processes in terms of the corporate goals.

Sensitivity analysis provided an interesting look at the behavior of the scenarios during variation of the selected parameters. This not only allows for the exploration of the affects of assumptions which may be under scrutiny but may also be used to run exploratory studies of potential scenarios that may occur in the future. These types of future scenarios may be useful to those who are attempting to plan future products or develop new technology by providing some guidelines for performance comparison.

The consumer imaging LCA has provided two additional aspects of environmental assessment that are of particular interest in strategic planning. First is the ability to relate functional units to environmental impacts. This link allows strategists to assess systems on a strategic level while maintaining the connection to the ultimate goal of products; that is, to provide value to the customer. Additionally, the broad perspective of LCA makes it useful in assessing the environmental impacts outside the gates of a particular company. Accounting for upstream impacts involved in mining and material processing as well as the product use phase and end of life allows a more accurate picture of the true environmental impacts of a companies activities.

Conclusions

There are many factors that need to be considered when evaluating strategic business issues. For environmental issues, some of these factors include government regulation, regions of operations, consumer issues and shareholder interests. While this study does not address many of these factors, it does provide an interesting capability. That is, linking high level strategic issues with process level, potentially production line level, information. Especially in larger companies, those developing corporate policy and strategy may be somewhat insulated from those handling the day to day process information. Improving the communication of information between the two groups has the potential to improve the company's environmental performance by allowing for better decision making throughout the company.

Additionally, the parameterization that was used in this study for sensitivity analysis could be expanded and used to explore different strategic scenarios. Consumer habits, market projections and distribution options could be incorporated into this parameterization scheme. Strategic scenarios could then be evaluated by manipulating these parameters for each scenario that is explored. Sourcing options, market fluctuations or trends, business models (leasing vs. purchase) and expanding into new markets could all be investigated in this manner. This sort of study could provide insights not only regarding these subjects, but might also provide an opportunity to further evaluate LCA for use in strategic assessment.

5.2 Validation

<u>ISO Standards</u>

Part of the validation for this particular study focuses on the ISO standards for Life Cycle Assessment. These standards are found in ISO 14040-3 and cover the principles and framework, goal and scope definition, inventory analysis, impact assessment and interpretation of LCA studies. Life cycle assessment, as an iterative process, requires continued reference and updating of the goals and scope of the assessment throughout the processes. Much of the validation language in the ISO standards deals with relating results to the goals and scope of the study itself. During the process of the assessment the goals and scope must be kept in mind and may be modified as the study progresses. Validation measure within the standards often refer to placing the results into the correct context given the goal, scope and limitations of the many factors involved in life cycle assessment.

ISO 14040 provides framework for the assessment. This framework defines several points that LCA should cover. Regarding the scope of an LCA, the standard defines several issues. First, the study should systematically and adequately address the environmental aspects of product systems from raw material acquisition to final disposal. Second, the scope, assumptions, methodologies and descriptions of data quality should all be transparent. Additionally, provisions are mandated for respect of confidentiality and proprietary matters.

In accordance with this first standard, the scope of this study was thoroughly defined. Life cycle stages were defined in the methodology section as upstream, distribution, use and end of life. Impact categories, while far from a full representation of all potential environmental impacts, do provide a cross section of impacts from gas, solid and liquid compartments and address both natural resource depletion and environmental pollution. Presentation of goal and scoping activities earlier in this document ensure that these activities were transparent. The normalization of the results that are presented helps protect the confidentiality of the data that was acquired through various sources.

Mandatory elements of the impact assessment include the selection of categories, indicators and characterization models, assignment of LCI results and calculation of category indicator results. These mandatory elements were completed and reported in the methodology section. Additionally, normalization of the results was completed to help protect confidentiality of some of the data that was included in the process models. This particular report was never meant to provide information to be utilized for any comparative assertion disclosed to the public. An external expert review was not completed both in part to protect proprietary data and because a public comparative assertion is not sought.

Assumptions are required for the completion of any LCA. Of special importance are those assumptions that have great potential to influence the results. In this study, those types of assumptions were selected for a sensitivity analysis. This analysis was completed and reported at the end of the results section. Notable results of this sensitivity analysis were taken into account during the development of the conclusions and future work areas.

Industry Commentary

Additional validation for this study comes in the form of commentary from Jay Mathewson from Kodak. Mr. Mathewson has participated in several Kodak internal LCA studies, was essential to developing this work and is extremely familiar with the studies methodology and results. The following section represents his view on the validity of this study.

A first step in assessing the validity of any LCA study is to evaluate the study with the international standards in mind. This study is consistent with ISO standards as well as the goals and scope defined for the study. The functional unit and boundaries that were established in the goal and scoping activities have been maintained throughout the study. The transparency provided by the methodology section is also critical to validity of this study. Also of importance is that the results and conclusions that are made are within the bounds of these goals and scope.

The structure of the life cycle inventories and data sources are also of importance for a study of this kind. Consistency across models that are to be compared is critical. For example, if two models both use injection molding to manufacture a similar part, the data source and life cycle inventories for both models should be the same, unless specific justification can be made for them being. This study maintains this consistent use of data sources across various process models. For example, the same battery life cycle inventory data and plastic manufacturing data was used for both digital and film cameras.

The assumptions made in a particular study can drastically influence the results. In a valid study, these assumptions should be transparent and their influence should be examined. The parameter assumptions that were made in this study grounded in either design specifications for lifetime and usage parameters or actual transportation modes and distances for the distribution phases. The sensitivity analysis explores these parameters and how they affect the results of the study.

Finally, the results of a study should be evaluated against expectations that one may have. The result of no clear winner is not a surprise here; with such a difference in technologies (digital vs. film) and a selection of different environmental impacts, a clear winner may not be expected. If it was simply a comparison between retail and wholesale printing, one may expect a clear winner because the systems utilize similar types of material and energy flows, just in different numbers. Additionally, the results are all in the same ballpark, as are the costs for film cameras, digital cameras and different types of prints. While cost is not directly related to environmental performance, it at times, can used as a rough comparison since cost of energy and materials are significant drivers of a products end cost.

One obvious shortcoming of this study is not fully evaluating the true differences in digital and film imaging. Digital imaging offers the user many more options than film imaging in how the user stores, manages and edits the image. This was due, in part to the focus of this study and attempting to evaluate the core functions of image capture, processing and output. Additionally, LCA studies focus on a comparison based on a single functional unit. In order to maintain a close functional unit between the two technologies, the functions were limited to the lowest common denominators between the two. While this does limit the scope of the study, it should not be seen as a stroke against its validity. The changes that digital imaging has introduced in how people use, manage and share images dramatically differ from the existing systems in film imaging. These changes are significant enough to justify further study.

5.3 Future Work

Further efforts could be directed in several areas. First of all, life cycle inventory data can be updated and improved. The two phases that impacted the results the most, upstream and use phase, also could be improved with some further investigation. This study was undertaken from the point of view of a rather simple functional unit, the capture, processing and output of a single image. Digital imaging, however, has spawned a myriad of different activities. These activities and the influence of the internet are quite different functions than those of traditional film imaging. Further examination of these differences may provide not only information about the impacts of the activities themselves, but also insights regarding technologies influence on human behavior.

Upstream data, which has been aggregated in this study, could be broken out to show impacts related to mining, material processing and manufacturing. One of the challenges involved in pursuing this would include the number of different parties that may have to be involved. With data from a variety sources, including database entries, external reports and internal reports, further separating life cycle phase data would be extremely challenging. Unless there were significant needs to break out the life cycle phase more, the difficulty and cost of activity may be prohibitive. If general improvements were desired the focus may be better off placed elsewhere, such as the use phase model.

The use phase in this study was, by design, a simple model. Further development of a more realistic use model, especially on the digital side, could yield some interesting results. For example, actual consumer usage habits could be incorporated and then compared to these results as a baseline. This could be especially useful in drafting any sort of consumer communications regarding use phase impacts and potential means to reduce them. Such a study could provide an opportunity to investigate some of the additional functions that digital photography allows, such as sharing, editing and storage of images.

With many digital cameras having the ability to capture both still images and video, combined with the influence of the internet, the options consumers have of editing, modifying and sharing images and videos have dramatically altered the consumer imaging world. These new functions have pushed consumer imaging beyond the functions of image capture, processing and output. Beyond a relative comparison of different technologies, this phenomenon presents the opportunity to study the introduction of new technology, with new capabilities on the consumer. Understanding the influence of this new technology may provide insights to how best to introduce other new technologies to consumers. These insights could potentially improve not only the environmental performance of systems via consumer habits, but also help in understanding the adoption of new technology in order to make new products and services more successful.

Finally, the strategic questions explored in the third thesis question could also be probed a bit deeper. While the usefulness of LCA in this domain has been demonstrated, the application of this work to specific strategic scenarios was not done. Using this baseline data, scenarios could be explored to provide further insights in strategic decisions. For example, issues regarding sourcing of materials and potentially moving manufacturing facilities could be investigated. With economic drivers moving some manufacturing out of the United States, these are very real and important issues that could be assessed with this method.

5.4 Closure and Lessons Learned

After completing the study, it is important to evaluate the entire process of completing the study, not just the results of the analysis. For this evaluation, there are several important issues. After assessing the results of the study and the assumptions made, there is the larger question of how appropriate is the method itself for the application and what limitations it has. Beyond the results of the study, what can be learned from the experience, such as the limitations of the study or what could be done differently in the future is also of importance.

When looking backward at the appropriateness of a completed study, it is important to keep an open mind and consider both the positive and negative aspects of the study. On the positive side, LCA maintains an entire life cycle perspective. This is critical in any sort of comparative assessment because of the potential for a different technology or business strategy to shift environmental impacts from one phase to another. Another benefit of LCA is the concept of a functional unit. This concept links the environmental impacts not to a single unit of product, but directly with the function that the consumer is interested in. Identifying these key functions as a basis for comparison is of critical importance when comparing different means of instantiating the functions. For example, service systems, such as retail or wholesale image printing, do not have a physical product system that the consumers own to provide the function of image output. Linking environmental output to these functions instead of a physical device or product is necessary to comparing these different business options.

There are also several areas where the LCA may have not quite been appropriate or had limitations in this study. While the strict focus on functional unit may be a benefit in certain areas, it can be a detriment in others. First, the focus on strict function of image capture, processing and output does not address the fundamental differences between film and digital imaging technologies. While some technologies may provide nearly identical functions to the user, film imaging and digital imaging have several differences. The extended functions digital imaging provides in terms of storing, managing, editing and sharing images is enough of a difference, that a comparison of the two technologies is not, in the strictest sense, a comparison of functionally equal technologies. Another one of the limitations of this study is that it uses an individual perspective that does not address society-wide concerns. It does not explore how populations are using and influencing the technology and services that are made possible with digital imaging. This method identifies individual level drivers, but ignores how these activities influence entire populations; a larger study would be helpful in this area, especially since the concept of product service systems that rely on these larger populations. For such a study, data of how a population is using these different technologies would be necessary, but this study could provide a baseline for further investigation.

There are many lessons that have been learned from completing this study. When developing the LCA data with Jay Mathewson at Kodak, the importance of institutional knowledge of a company became obvious. The simple knowledge of who in the organization might have the data required, and, perhaps more importantly having a working relationship with these people can greatly influence the success or failure of such an endeavor. Secondly, from there are lessons to be learned from the structure and standards of LCA. LCA is a data intensive undertaking and when first starting such a project there may be uncertainty as to where the data be found, what form it will be in and even, whether the data exist at all. The authors of the ISO standards understood this and suggested an iterative process in the goal and scoping activities of the study. The concept of creating and maintaining semi-flexible goals during a project where there is a fair amount of uncertainty on what is actually possible can be of value outside the area of LCA. This concept not only allows one to adjust goals to the availability of data and other situations that may arise, but it also keeps the project on track with foundational goals and motivations. Finally, the importance of outside input during not only the development of this thesis, but also during the process of the study was of great importance. Participation from the Kodak LCA steering team, other Kodak employees, fellow students and professors provided much needed perspective, advice and support that improved not only the study itself and this thesis, but also the experience of completing these activities. The lesson in this is to ensure that these types of inputs are solicited in future activities.

APPENDIX A – NORMALIZED SCENARIO RESULTS TABLES

The following table contains the normalized impact results for each of the ten consumer imaging scenarios. The results include four impact categories, greenhouse effect, water use, waste generation and energy use. The results presented in this table are normalized in order to disguise some results that may contain proprietary information.

	Normalized Results			
Scenario Results	**GE**	**WU**	**WG**	**EU**
	kg CO2 eq. / kg CO2 eq	m^3 / m^3	kg / kg	MJ / MJ
Film Capture to Retail Print	1.00E+00	7.45E-03	9.52E-02	9.80E-01
Film Capture to Wholesale Print	6.13E-01	6.44E-03	6.85E-02	6.51E-01
Digital Capture CRT Upload to Retail Print	6.77E-01	2.05E-01	2.41E-01	7.95E-01
Digital Capture CRT Upload to Wholesale Print	4.67E-01	2.05E-01	2.39E-01	6.19E-01
Digital Capture LCD Upload to Retail Print	6.41E-01	5.95E-02	2.19E-01	6.79E-01
Digital Capture LCD Upload to Wholesale Print	4.31E-01	5.94E-02	2.17E-01	5.03E-01
Digital Capture to CRT Inkjet Print	4.14E-01	1.99E-01	1.00E+00	5.85E-01
Digital Capture to LCD Inkjet Print	3.82E-01	6.82E-02	9.80E-01	4.81E-01
Digital Capture to Display CRT	5.14E-01	1.00E+00	3.25E-01	1.00E+00
Digital Capture to Display LCD	3.34E-01	2.71E-01	1.65E-01	4.20E-01

APPENDIX B NORMALIZED PROCESS RESULTS TABLES

The following table contains the normalized process results for each of the twelve processes that make up the scenarios. The results presented in this table are normalized in order to disguise some results that may contain proprietary information. These process results are divided into four life cycle phases including upstream, distribution, use and end of life. The four impact categories that are included are energy use, greenhouse emission, waste generation and water use.

Normalized Process Results	Impact Category	Normalized Results				Units
		Upstream	Distribution	Use	End of Life	
CRT Display	EU	1.00E+00	1.70E-02	4.58E-01	9.97E-05	MJ / MJ
CRT Inkjet Output	EU	4.61E-01	2.16E-02	3.25E-01	2.13E-04	MJ / MJ
Digital Capture	EU	3.86E-02	6.17E-02	2.96E-02	4.94E-06	MJ / MJ
Film Capture	EU	3.93E-03	7.32E-04	3.51E-01	4.07E-06	MJ / MJ
LCD Display	EU	2.72E-01	8.34E-03	2.65E-01	3.61E-05	MJ / MJ
LCD Inkjet Output	EU	3.31E-01	2.00E-02	2.91E-01	2.02E-04	MJ / MJ
PC/CRT Processing	EU	2.00E-01	3.39E-03	9.15E-02	1.99E-05	MJ / MJ
PC/LCD Processing	EU	5.43E-02	1.67E-03	5.29E-02	7.21E-06	MJ / MJ
Retail Film Processing	EU	2.31E-03	2.87E-04	3.64E-01	4.66E-06	MJ / MJ
Retail Printing	EU	1.41E-03	7.32E-04	8.48E-01	1.22E-05	MJ / MJ
Wholesale Film Processing	EU	1.55E-04	1.31E-05	1.20E-01	2.25E-07	MJ / MJ
Wholesale Printing	EU	1.12E-04	1.96E-05	5.69E-01	3.46E-07	MJ / MJ
CRT Display	GE	2.20E-01	1.21E-02	6.28E-01	9.49E-05	kg CO2 eq. / kg CO2 eq
CRT Inkjet Output	GE	2.89E-01	2.05E-02	3.57E-01	2.03E-04	kg CO2 eq. / kg CO2 eq
Digital Capture	GE	3.82E-02	7.25E-02	2.29E-02	4.69E-06	kg CO2 eq. / kg CO2 eq
Film Capture	GE	2.81E-03	6.14E-04	4.16E-01	3.87E-06	kg CO2 eq. / kg CO2 eq
LCD Display	GE	1.43E-01	5.39E-03	3.63E-01	3.43E-05	kg CO2 eq. / kg CO2 eq
LCD Inkjet Output	GE	2.75E-01	1.93E-02	3.10E-01	1.92E-04	kg CO2 eq. / kg CO2 eq
PC/CRT Processing	GE	4.40E-02	2.43E-03	1.26E-01	1.90E-05	kg CO2 eq. / kg CO2 eq
PC/LCD Processing	GE	2.85E-02	1.08E-03	7.26E-02	6.86E-06	kg CO2 eq. / kg CO2 eq
Retail Film Processing	GE	2.53E-03	2.73E-04	5.07E-01	4.43E-06	kg CO2 eq. / kg CO2 eq
Retail Printing	GE	1.54E-03	6.96E-04	1.00E+00	1.16E-05	kg CO2 eq. / kg CO2 eq

Wholesale Film Processing	GE	1.91E-04	1.24E-05	1.67E-01	2.14E-07	kg CO2 eq. / kg CO2 eq
Wholesale Printing	GE	1.38E-04	1.86E-05	5.97E-01	3.30E-07	kg CO2 eq. / kg CO2 eq
CRT Display	WG	1.75E-01	6.84E-04	2.93E-05	4.53E-02	kg / kg
CRT Inkjet Output	WG	1.00E+00	1.31E-04	5.81E-02	9.69E-02	kg / kg
Digital Capture	WG	2.19E-01	2.17E-04	7.07E-03	2.24E-03	kg / kg
Film Capture	WG	1.91E-04	1.47E-05	7.08E-03	1.85E-03	kg / kg
LCD Display	WG	5.13E-02	4.21E-04	1.69E-05	1.64E-02	kg / kg
LCD Inkjet Output	WG	9.78E-01	8.36E-05	5.81E-02	9.17E-02	kg / kg
PC/CRT Processing	WG	3.50E-02	1.37E-04	5.86E-06	9.06E-03	kg / kg
PC/LCD Processing	WG	1.03E-02	8.42E-05	3.39E-06	3.28E-03	kg / kg
Retail Film Processing	WG	2.36E-08	1.24E-07	6.01E-02	2.05E-03	kg / kg
Retail Printing	WG	1.44E-08	3.15E-07	5.52E-02	5.23E-03	kg / kg
Wholesale Film Processing	WG	1.61E-09	5.62E-09	2.75E-02	9.34E-05	kg / kg
Wholesale Printing	WG	1.16E-09	8.43E-09	5.79E-02	1.40E-04	kg / kg
CRT Display	WU	1.00E+00	1.09E-03	3.30E-01	1.26E-05	m^3 / m^3
CRT Inkjet Output	WU	1.86E-01	2.26E-03	7.61E-02	2.70E-05	m^3 / m^3
Digital Capture	WU	4.37E-04	2.47E-04	3.38E-05	6.26E-07	m^3 / m^3
Film Capture	WU	1.64E-05	4.79E-05	1.96E-03	5.16E-07	m^3 / m^3
LCD Display	WU	1.69E-01	4.34E-04	1.91E-01	4.57E-06	m^3 / m^3
LCD Inkjet Output	WU	3.67E-02	2.14E-03	5.12E-02	2.56E-05	m^3 / m^3
PC/CRT Processing	WU	2.00E-01	2.17E-04	6.59E-02	2.53E-06	m^3 / m^3
PC/LCD Processing	WU	3.38E-02	8.69E-05	3.81E-02	9.14E-07	m^3 / m^3
Retail Film Processing	WU	6.53E-06	3.65E-05	1.32E-03	5.91E-07	m^3 / m^3
Retail Printing	WU	3.99E-06	9.28E-05	6.44E-03	1.55E-06	m^3 / m^3
Wholesale Film Processing	WU	3.18E-07	1.66E-06	1.15E-04	2.85E-08	m^3 / m^3
Wholesale Printing	WU	2.28E-07	2.49E-06	6.43E-03	4.39E-08	m^3 / m^3

APPENDIX C SENSITIVITY ANALYSIS SCENARIO RESULTS TABLES

The following tables are the results of the sensitivity analysis for the nineteen lifetime and usage parameters. These are presented for each of the parameters with the two variations of the parameters and the results of the variation on the scenario results. The values in the table are the percent change in the four impact categories for each of the ten consumer imaging scenarios.

	50% of Base				200% of Base			
Scenario Results	**GE**	**WU**	**WG**	**WU**	**GE**	**WU**	**WG**	**WU**
Film Camera	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.18%	0.65%	1.56%	0.30%	-0.09%	-0.33%	-0.78%	-0.15%
FC/W	0.29%	0.76%	2.17%	0.45%	-0.15%	-0.38%	-1.08%	-0.22%
DC/CR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Absolute Value Sums	0.47%	1.41%	3.73%	0.74%	0.23%	0.71%	1.86%	0.37%
Absolute Value Sum Total	6.35%	Average:	1.59E-03		3.17%	Average:	7.93 E-04	
	50% of Base				**200% of Base**			
Scenario Results	**GE**	**H2O Use**	**WG**	**E Use**	**GE**	**H2O Use**	**WG**	**E Use**
Flim	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	20.43%	19.43%	0.34%	20.54%	-10.21%	-9.72%	-0.17%	-10.27%
FC/W	33.34%	22.48%	0.48%	30.93%	-16.67%	-11.24%	-0.24%	-15.47%
DC/CR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Absolute Value Sums	53.77%	41.91%	0.82%	51.48%	26.88%	20.95%	0.41%	25.74%
Absolute Value Sum Total	147.97%	Average:	0.37 E-02		73.99%	Average:	1.85E-02	
	50% of Base				**200% of Base**			
Scenario Results	**GE**	**WU**	**WG**	**WU**	**GE**	**WU**	**WG**	**WU**
Battery (Film Camera)	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**

FC/R	1.11%	0.32%	5.03%	1.76%	-0.56%	-0.16%	-2.52%	-0.88%
FC/W	1.82%	0.37%	6.99%	2.66%	-0.91%	-0.19%	-3.50%	-1.33%
DC/CR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Absolute Value Sums	2.93%	0.69%	12.03%	4.42%	1.47%	0.35%	6.01%	2.21%
Absolute Value Sum Total	20.07%	Average:	5.02E-03		10.03%	Average:	2.51E-03	
	50% of Base				**200% of Base**			
Scenario Results	**GE**	**WU**	**WG**	**WU**	**GE**	**WU**	**WG**	**WU**
Digital Camera	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
FC/W	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CR	8.46%	0.25%	66.52%	7.87%	-4.23%	-0.13%	-33.26%	-3.93%
DC/CW	12.26%	0.25%	66.99%	10.09%	-6.13%	-0.13%	-33.50%	-5.05%
DC/LR	8.94%	0.86%	73.23%	9.21%	-4.47%	-0.43%	-36.62%	-4.61%
DC/LW	27.48%	0.94%	82.13%	27.96%	-13.74%	-0.47%	-41.06%	-13.98%
DC/CI	13.83%	0.26%	16.03%	10.68%	-6.91%	-0.13%	-8.01%	-5.34%
DC/LI	15.00%	0.75%	16.35%	12.99%	-7.50%	-0.38%	-8.18%	-6.50%
DC/CD	11.13%	0.05%	49.31%	6.25%	-5.57%	-0.03%	-24.65%	-3.13%
DC/LD	17.17%	0.19%	96.91%	14.87%	-8.58%	-0.10%	-48.45%	-7.43%
Absolute Value Sums	114.27%	3.56%	467.45%	99.91%	57.13%	1.78%	233.73%	49.96%
Absolute Value Sum Total	685.19%	Average:	0.171		342.59%	Average:	8.57E-02	
	50% of Base				**200% of Base**			
Scenario Results	**GE**	**WU**	**WG**	**WU**	**GE**	**WU**	**WG**	**WU**
Battery (Digital Camera)	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
FC/W	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CR	1.75%	0.01%	2.12%	2.32%	-0.88%	-0.01%	-1.06%	-1.16%
DC/CW	2.54%	0.01%	2.14%	2.98%	-1.27%	-0.01%	-1.07%	-1.49%
DC/LR	1.85%	0.04%	2.33%	2.72%	-0.93%	-0.02%	-1.17%	-1.36%
DC/LW	5.70%	0.05%	2.62%	8.25%	-2.85%	-0.02%	-1.31%	-4.13%
DC/CI	2.87%	0.01%	0.51%	3.15%	-1.43%	-0.01%	-0.26%	-1.58%
DC/LI	3.11%	0.04%	0.52%	3.83%	-1.56%	-0.02%	-0.26%	-1.92%
DC/CD	2.31%	0.00%	1.57%	1.84%	-1.15%	0.00%	-0.79%	-0.92%
DC/LD	3.56%	0.01%	3.09%	4.39%	-1.78%	-0.01%	-1.54%	-2.19%
Absolute Value Sums	23.69%	0.18%	14.90%	29.49%	11.85%	0.09%	7.45%	14.74%
Absolute Value Sum Total	68.25%	Average:	1.71E-02		34.13%	Average:	8.531E-03	
	50% of Base				**200% of Base**			
Scenario Results	**GE**	**WU**	**WG**	**WU**	**GE**	**WU**	**WG**	**WU**
Retail Film Processing Equipment	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.15%	0.44%	1.56%	0.17%	-0.07%	-0.22%	-0.78%	-0.08%

FC/W	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Absolute Value Sums	0.15%	0.44%	1.56%	0.17%	0.07%	0.22%	0.78%	0.08%
Absolute Value Sum Total	2.31%	Average:	5.77E-04		1.16%	Average:	2.89E-04	

	50% of Base				**200% of Base**			
Scenario Results	**GE**	**WU**	**WG**	**WU**	**GE**	**WU**	**WG**	**WU**
Wholesale Film Processing Equipment	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
FC/W	0.02%	0.02%	0.10%	0.02%	-0.01%	-0.01%	-0.05%	-0.01%
DC/CR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Absolute Value Sums	0.02%	0.02%	0.10%	0.02%	0.01%	0.01%	0.05%	0.01%
Absolute Value Sum Total	0.16%	Average:	3.88E-05		0.08%	Average:	1.94E-05	

	50% of Base				**200% of Base**			
Scenario Results	**GE**	**WU**	**WG**	**WU**	**GE**	**WU**	**WG**	**WU**
Digital Processing / Uploading Time	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
FC/W	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CR	-6.58%	-48.67%	-6.63%	-11.57%	13.16%	97.35%	13.25%	23.14%
DC/CW	-9.53%	-48.69%	-6.67%	-14.84%	19.06%	97.38%	13.35%	29.68%
DC/LR	-4.13%	-45.42%	-2.25%	-5.00%	8.26%	90.84%	4.50%	10.00%
DC/LW	-12.69%	-49.43%	-2.52%	-15.18%	25.38%	98.85%	5.04%	30.36%
DC/CI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Absolute Value Sums	32.93%	192.21%	18.07%	46.59%	65.85%	384.43%	36.14%	93.18%
Absolute Value Sum Total	289.80%	Average:	7.25E-02		579.60%	Average:	1.45E-01	

	50% of Base				**200% of Base**			
Scenario Results	**GE**	**WU**	**WG**	**WU**	**GE**	**WU**	**WG**	**WU**
CRT Monitor Lifetime	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
FC/W	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CR	2.48%	64.46%	9.94%	11.94%	-1.24%	-32.23%	-4.97%	-5.97%

DC/CW	3.59%	64.48%	10.01%	15.32%	-1.80%	-32.24%	-5.01%	-7.66%
DC/LR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CI	3.63%	59.63%	2.15%	14.53%	-1.81%	-29.81%	-1.07%	-7.27%
DC/LI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CD	16.31%	66.18%	36.86%	47.44%	-8.15%	-33.09%	-18.43%	-23.72%
DC/LD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Absolute Value Sums	26.01%	254.74%	58.96%	89.23%	13.00%	127.37%	29.48%	44.61%
Absolute Value Sum Total	428.94%	Average:	1.07E-01		214.47%	Average:	5.36E-02	
	50% of Base				**200% of Base**			
Scenario Results	**GE**	**WU**	**WG**	**WU**	**GE**	**WU**	**WG**	**WU**
PC Lifetime	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
FC/W	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CR	1.07%	8.77%	3.31%	4.02%	-0.54%	-4.39%	-1.65%	-2.01%
DC/CW	1.56%	8.78%	3.33%	5.15%	-0.78%	-4.39%	-1.67%	-2.58%
DC/LR	1.14%	30.27%	3.64%	4.70%	-0.57%	-15.14%	-1.82%	-2.35%
DC/LW	3.49%	32.94%	4.08%	14.27%	-1.75%	-16.47%	-2.04%	-7.13%
DC/CI	1.57%	8.12%	0.71%	4.89%	-0.79%	-4.06%	-0.36%	-2.44%
DC/LI	1.71%	23.66%	0.73%	5.94%	-0.85%	-11.83%	-0.36%	-2.97%
DC/CD	7.07%	9.01%	12.26%	15.95%	-3.53%	-4.50%	-6.13%	-7.97%
DC/LD	10.90%	33.25%	0.00%	37.94%	-5.45%	-16.63%	0.00%	-18.97%
Absolute Value Sums	28.50%	154.79%	28.06%	92.85%	14.25%	77.40%	14.03%	46.43%
Absolute Value Sum Total	304.20%	Average:	7.61E-02		152.10%	Average:	3.80E-02	
	50% of Base				**200% of Base**			
Scenario Results	**GE**	**WU**	**WG**	**WU**	**GE**	**WU**	**WG**	**WU**
LCD Monitor Lifetime	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
FC/W	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LR	1.26%	12.48%	0.86%	0.44%	-0.63%	-6.24%	-0.43%	-0.22%
DC/LW	3.87%	13.57%	0.96%	1.35%	-1.93%	-6.79%	-0.48%	-0.67%
DC/CI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LI	1.89%	9.75%	0.17%	0.56%	-0.95%	-4.88%	-0.09%	-0.28%
DC/CD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LD	12.08%	13.71%	0.00%	3.58%	-6.04%	-6.85%	0.00%	-1.79%
Absolute Value Sums	19.09%	49.50%	1.99%	5.93%	9.55%	24.75%	0.99%	2.97%
Absolute Value Sum Total	76.51%	Average:	1.91E-02		38.26%	Average:	9.56E-03	
	50% of Base				**200% of Base**			
Scenario Results	**GE**	**WU**	**WG**	**WU**	**GE**	**WU**	**WG**	**WU**
Photopaper	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	16.75%	55.18%	10.50%	23.30%	-8.38%	-27.59%	-5.25%	-11.65%
FC/W	27.34%	63.84%	14.59%	35.08%	-13.67%	-31.92%	-7.29%	-17.54%
DC/CR	24.75%	2.00%	4.15%	28.74%	-12.37%	-1.00%	-2.07%	-14.37%
DC/CW	35.85%	2.00%	4.18%	36.86%	-17.92%	-1.00%	-2.09%	-18.43%
DC/LR	26.14%	6.91%	4.56%	33.64%	-13.07%	-3.45%	-2.28%	-16.82%

DC/LW	38.85%	6.92%	4.60%	45.35%	-19.43%	-3.46%	-2.30%	-22.68%
DC/CI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Absolute Value Sums	169.69%	136.85%	42.57%	202.97%	84.84%	68.43%	21.28%	101.49%
Absolute Value Sum Total	552.07%	Average:	0.138		276.04%	Average:	6.9E-02	
	50% of Base				**200% of Base**			
Scenario Results	**GE**	**WU**	**WG**	**WU**	**GE**	**WU**	**WG**	**WU**
Retail Printing Equipment	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.12%	0.99%	3.97%	0.14%	-0.06%	-0.50%	-1.99%	-0.07%
FC/W	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CR	0.17%	0.04%	1.57%	0.17%	-0.09%	-0.02%	-0.78%	-0.08%
DC/CW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LR	0.18%	0.12%	1.73%	0.20%	-0.09%	-0.06%	-0.86%	-0.10%
DC/LW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Absolute Value Sums	0.47%	1.15%	7.26%	0.50%	0.24%	0.58%	3.63%	0.25%
Absolute Value Sum Total	9.39%	Average:	2.35E-03		4.69%	Average:	1.17E-03	
	50% of Base				**200% of Base**			
Scenario Results	**GE**	**WU**	**WG**	**WU**	**GE**	**WU**	**WG**	**WU**
Wholesale Printing Equipment	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
FC/W	0.01%	0.03%	0.15%	0.01%	-0.01%	-0.02%	-0.07%	-0.01%
DC/CR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CW	0.02%	0.00%	0.04%	0.01%	-0.01%	0.00%	-0.02%	-0.01%
DC/LR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LW	0.02%	0.00%	0.05%	0.02%	-0.01%	0.00%	-0.02%	-0.01%
DC/CI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Absolute Value Sums	0.05%	0.04%	0.24%	0.04%	0.03%	0.02%	0.12%	0.02%
Absolute Value Sum Total	0.37%	Average:	9.12E-05		0.18%	Average:	4.56E-05	
	50% of Base				**200% of Base**			
Scenario Results	**GE**	**WU**	**WG**	**WU**	**GE**	**WU**	**WG**	**WU**
Inkjet Printer	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
FC/W	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CI	33.48%	3.24%	76.40%	32.08%	-16.74%	-1.62%	-38.20%	-16.04%

DC/LI	36.32%	9.44%	77.94%	39.00%	-18.16%	-4.72%	-38.97%	-19.50%
DC/CD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Absolute Value Sums	69.79%	12.68%	154.35%	71.08%	34.90%	6.34%	77.17%	35.54%
Absolute Value Sum Total	307.89%	Average:	7.70E-02		153.95%	Average:	3.85E-02	
	50% of Base				**200% of Base**			
Scenario Results	**GE**	**WU**	**WG**	**WU**	**GE**	**WU**	**WG**	**WU**
Inkjet Cartridge	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
FC/W	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CI	1.88%	0.01%	0.08%	2.07%	-0.94%	-0.01%	-0.04%	-1.03%
DC/LI	2.04%	0.04%	0.08%	2.51%	-1.02%	-0.02%	-0.04%	-1.26%
DC/CD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Absolute Value Sums	3.92%	0.05%	0.16%	4.58%	1.96%	0.03%	0.08%	2.29%
Absolute Value Sum Total	8.71%	Average:	2.18E-03		4.36%	Average:	1.09E-03	
	50% of Base				**200% of Base**			
Scenario Results	**GE**	**WU**	**WG**	**WU**	**GE**	**WU**	**WG**	**WU**
Inkjet Paper	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
FC/W	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CI	25.03%	0.62%	4.12%	21.60%	-12.52%	-0.31%	-2.06%	-10.80%
DC/LI	27.15%	1.82%	4.21%	26.26%	-13.58%	-0.91%	-2.10%	-13.13%
DC/CD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Absolute Value Sums	52.18%	2.44%	8.33%	47.85%	26.09%	1.22%	4.16%	23.93%
Absolute Value Sum Total	110.80%	Average:	2.77E-02		55.40%	Average:	1.39E-02	
	50% of Base				**200% of Base**			
Scenario Results	**GE**	**WU**	**WG**	**WU**	**GE**	**WU**	**WG**	**WU**
Printing Time	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
FC/W	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CI	-11.46%	-47.93%	-1.43%	-15.21%	22.92%	95.86%	2.86%	30.42%
DC/LI	-8.19%	-43.96%	-0.45%	-7.70%	16.38%	87.92%	0.90%	15.40%
DC/CD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

DC/LD	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Absolute Value Sums	19.65%	91.89%	1.88%	22.91%	39.29%	183.77%	3.76%	45.83%
Absolute Value Sum Total	136.33%	Average:	3.41E-02		272.65%	Average:	6.82E-02	
	50% of Base				**200% of Base**			
Scenario Results	**GE**	**WU**	**WG**	**WU**	**GE**	**WU**	**WG**	**WU**
Display Time	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**	**% Change**
FC/R	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
FC/W	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LW	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/LI	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC/CD	-43.28%	-49.97%	-24.56%	-45.95%	86.56%	99.95%	49.12%	91.91%
DC/LD	-39.64%	-49.90%	0.00%	-40.37%	79.28%	99.80%	0.01%	80.74%
Absolute Value Sums	82.92%	99.87%	24.56%	86.33%	165.83%	199.75%	49.13%	172.65%
Absolute Value Sum Total	293.68%	Average:	7.34E-02		587.36%	Average:	0.147	

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